Presence and persistence of the Peregrine Falcon and Lanner Falcon in South Africa

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ABSTRACT

The Peregrine Falcon (*Falco peregrinus*) and the Lanner Falcon (*Falco biarmicus*) are small to medium-sized birds that display behavioural plasticity to diverse environments and are widely distributed throughout sub-Saharan Africa, where they occur sympatrically. Peregrine Falcons have an almost global distribution, and Lanner Falcons have an Afro-tropical distribution. The aim of this thesis was to determine the presence and persistence of the Peregrine Falcon and the Lanner Falcon across South Africa. This study leverages data from the Southern African Bird Atlas Project (SABAP1 and SABAP2), social media platforms (Facebook®, eBird®, and iNaturalist®), and literature (sourced from Google Scholar®, Web of Science®, Scopus®, and PUBMED®) to investigate the distribution and relative abundance of the Peregrine Falcon and Lanner Falcon across South Africa. Both species, often coexisting across sub-Saharan Africa, share similar habitat preferences and prey species selection. Peregrine Falcons' behavioural plasticity to urban environments highlights its resilience, whereas Lanner Falcons displayed mixed responses suggesting targeted conservation strategies to mitigate the impacts of habitat fragmentation, land use changes, and urban encroachment. Peregrine Falcons had a more restricted distribution within South Africa than Lanner Falcons, and both species had distributions within urban areas. The presence of Peregrine Falcons negatively influenced Lanner Falcons distributions and abundance. Lanner Falcons were more frequently observed but remained understudied in comparison. Overall, both species are understudied in Africa, particularly in South Africa. Research on both falcons focussed on their breeding ecology and the health of the species with a focus on egg-shell thickness in response to environmental factors and parasitic studies. Research was primarily based in Europe and North America, and both species remain understudied in other regions of geographical distribution. Research techniques for monitoring and data collection relied on observational data and biological and genetic sampling. Established monitoring techniques are commonly

used, and new novel approaches such as citizen science remain underutilised but with growing interest. The findings in this thesis highlight the complex relationship between urbanisation, species competition, social interactions, ecology, behaviour, and habitat preferences in shaping these falcons' distribution and population trends.

PREFACE

The data described in this thesis were collected in KwaZulu-Natal Province, Republic of South Africa, from February 2023 to November 2024. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Colleen T Downs and Dr Mfundo ST Maseko.

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

Kyle Govender

January 2025

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

……..

Prof Colleen T Downs

Supervisor

January 2025

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DECLARATION 1 - PLAGIARISM

I, Kyle Govender, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
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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- To be submitted

Systematic review of Peregrine Falcon and Lanner Falcon research globally, and specifically in South Africa

K Govender, MST Maseko & CT Downs

Author contributions:

KG conceived the paper with MSTM and CTD. CTD sought funding. KG collected and analysed data, and wrote the draft paper. MSTM and CTD contributed valuable comments to analyses and the manuscript.

PUBLICATION 2- Submitted- Provisionally accepted

Urban persistence and species interactions: Diverging trends in the Peregrine Falcon and Lanner Falcon abundance across southern Africa using the Southern African Bird Atlas Project

K Govender, MST Maseko, ATK Lee & CT Downs

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PUBLICATION 3- To be submitted

Using social media to document the persistence of the Peregrine Falcon and the Lanner Falcon across South Africa

K Govender, MST Maseko & CT Downs

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KG conceived the paper with MSTM and CTD. CTD sought funding. KG collected and analysed data, and wrote the draft paper. MSTM and CTD contributed valuable comments to analyses and the manuscript.

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January 2025

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CHAPTER 1

Introduction

1.1 Background

Urbanisation refers to a change in land use with increased anthropogenic structures and generally follows the movement of human populations from rural areas to urban built areas (McKinney 2010; Meffert and Dziock 2013; Biłozor and Cieślak 2021). Higher human population densities in cities are beneficial because communities can coordinate efforts such as education, transportation, recycling, and the general advancement of human civilisations (Browne 2014; Turok and Borel-Saladin 2014; Duranton and Puga 2020). This includes better access to medical care, family planning, longer life expectancies, and more access to resources (Browne 2014; Zhang 2016; Yusoff 2020). The features of human urban landscapes are characterised by anthropogenic structures such as roads, buildings, and energy infrastructures (Zhang 2016; Maphalala et al. 2021). The typical effects of urbanisation worldwide have generally led to the loss of natural habitats, habitat fragmentation, loss of indigenous species, urban stressors (such as noise, lights, and pollution), modification of natural cycles, and introduction of domestic pets that may act as predators or in some cases prey (Meffert and Dziock 2013; Odewumi et al. 2020; McPherson et al. 2021). Urban landscapes are combinations of complex habitat mosaics which include a mix of streets, buildings, paved surfaces, roads, and other infrastructures (which make up grey space) and the vegetation of the city (which make up green spaces) (Faeth et al. 2011; Magle et al. 2012; Soulsbury and White 2015; Downs et al. 2021). The urban matrix is not homogenous; there is a mix of lower and higher density clusters of buildings, varying sizes of green spaces that contain natural areas, managed parklands, gardens, and recreational areas, as well as linear structures such as anthropogenic structures like railways and roads and natural structures like rivers (Soulsbury and White 2015; Downs et al. 2021). Biodiversity in urban areas can directly be related to the

vegetative communities and the amount of green space in urban mosaic landscapes (Taylor et al. 2013; Łopucki et al. 2019).

Urban built expansion, however, encroaches on wildlife habitats all around the world. Continuous and growing pressure is placed on wildlife because of the deterioration of natural environments and the growing rate of urban built environments (Pettersen 2022; Fraissinet et al. 2023). The impact of urban built landscapes can result in changes to ecosystem processes and structure, leading to the existing natural habitats becoming fragmented or even lost (Soulsbury and White 2015; Theodorou 2022). The high population density in cities may also negatively impact the environment because of the larger population numbers; there may be a strain on the natural resources present in these areas as well as generating more pollution, such as water and air pollution (Kark et al. 2007; Pettersen 2022). The physicochemical properties of the environment can also be changed or altered; these include soil, water, nutrient cycling, and temperatures (Soulsbury and White 2015; Fraissinet et al. 2023). Urban built areas can be challenging for wildlife with regards to disruptions to their natural habitats, light and noise pollution, as well as changes to diet and predators resulting from changes in the presence of wildlife in these urban built areas, resulting in impacts of interactions at all levels (Soulsbury and White 2015; Reynolds et al. 2019). The effects of urban built areas can be seen as a threat to ecosystems and wildlife, resulting in many species being displaced and becoming urban avoiders (Davis 1976; Faeth et al. 2011). Loss or modifications of natural habitats and resources because of urban built landscapes are the main disadvantages posed to wildlife, which can lead to the extinction of local species or even result in changes to the distribution of species entirely (Taylor et al. 2013). Anthropogenic structures in urban built areas also threaten birds of prey by increasing collision risks for the birds that occupy urban spaces (Maphalala et al. 2021).

Urban ecology is relatively new and ever-changing, and the degree of interaction between wildlife and humans within urban mosaic landscapes remains understudied; however, all wildlife in these landscapes will interact with humans to some extent (Soulsbury and White 2015; Faeth et al. 2011). With the increasing numbers of people living in urban-built areas, it has become common for people to live and work in a proximity that is close to animals whose native habitats have been disrupted or lost because of urban built landscapes. As the rate of urban built areas increases, there is a growing need to understand the type and extent of interactions between humans and wildlife to control, decrease, or even increase the level of these interactions (Soulsbury and White 2015; König et al. 2020). The dynamic relationship between humans and wildlife in urban-built areas remains complex (Taylor et al. 2013). The conflicts between humans and wildlife within urban built areas also need to be understood; these include physical attacks, damage to property, the transmission of diseases, and interactions between domestic animals and wildlife (Soulsbury and White 2015; König et al. 2020). Birds in urban built areas often have frequent but varying levels of interaction with humans, such as supplementary feeders being used for birds or humans' efforts to control or remove/eradicate species of birds in urban built spaces (Taylor et al. 2013). Birds can be used as biodiversity indicators and can provide indications of changes or stress in urban-built ecosystems because they are sensitive to these changes and are easily visible in urban landscapes (Taylor et al. 2013).

With regards to biodiversity, increases in urban-built landscapes will typically act to reduce species richness (but not always the case in the Global South (Downs et al. 2021)); however, urban-built areas also result in new opportunities, new ecological niches, and new nest sites that allow some species of birds to thrive and become urban exploiters (Kark et al. 2007; Lee et al. 2021). Rapid urban built environment increases can create new challenges for biodiversity, resulting in species adapting, relocating, or even becoming locally extinct

(Sumasgutner et al. 2020). There is a general trend for biotic diversity to decrease from rural to urban areas, creating an urban-rural gradient; however, the patterns of biotic diversity can still vary depending on urban built landscape intensity or the degree of green spaces (natural and managed) in the urban mosaic landscape (Soulsbury and White 2015; Faeth et al. 2011; Downs et al. 2021). Several species have become urban-dwelling wildlife populations, such as sparrows, pigeons, starlings, rats and small mammals, taking advantage of the relative abundance of food, shelter, and warmer temperatures (Faeth et al. 2011; Palacio 2020). These urban-built exploiters (animals that take advantage of resources in urban areas) can establish and maintain stable species populations in urban-built areas. However, some species, such as birds, can change their dependence to become more reliant and even dependent upon the resources available in urban-built landscapes (Fraissinet et al. 2023).

Some species are able to persist in urban built environments, with a predominance of birds becoming urban exploiters (Pettersen 2022). The persistence of biodiversity in urban built areas has been found to be beneficial for humans (Taylor et al. 2013). Wildlife in urban built areas contributes to ecosystem services in these areas and provides various benefits to humans, including benefits to humans' well-being and health (Magle et al. 2012; Soulsbury and White 2015). Urban-built areas have limited space, and thus, the relationship between humans and wildlife can mutually have positive and negative aspects for both parties (Magle et al. 2012; Taylor et al. 2013). Recreational activities that involve wildlife can be an advantage in ensuring the persistence of wildlife in urban mosaic landscapes with green spaces; these activities include bird watching, wildlife photography, ecotourism, and feeding wildlife (e.g., provision of birdfeeders) (Taylor et al. 2013; Perry et al. 2020). These interactions can elicit positive emotional responses, creating a positive advantage in improving humans' mental health and well-being (Taylor et al. 2013; Cameron et al. 2020).

Species in urban mosaic landscapes can differ in physiological, ecological, and even genetic traits, but differences in behavioural traits or plasticity are most commonly noticed (Kark et al. 2007; Magle et al. 2012; Theodorou 2022). Urban-built dwelling animal populations are also subject to aggression and competition. Selection pressures prevent several animal species from occupying, breeding, or foraging for food in urban built areas of urban mosaic landscapes (Kark et al. 2007; Palacio 2020). These animals are urban-built avoiders.

In many southern hemisphere countries such as South Africa, urban environments are designed to be mosaic landscapes with anthropogenic infrastructure like roads and buildings and green spaces which are natural and managed (Garden et al. 2006; Turok and Borel-Saladin, 2014; Pérez et al. 2019; Downs et al. 2021; McPherson et al. 2021). Many urban mosaic landscapes in South Africa have a variety of flora and fauna that have persisted in these green spaces (McPherson et al. 2016a,b, 2019; Wreford et al. 2017; Alexander et al. 2019a,b,c; Zungu et al. 2019, 2020a,b; Maseko et al. 2019, 2020; Anderson et al. 2020; Downs et al. 2021; Maseko et al. 2023). Here some species have even increased their population density in these areas compared with more rural natural habitats (McPherson et al. 2021). Other species show behavioural plasticity in behaviour and diet, such as the Cape or South African large-spotted genet (*Genetta tigrina*) (Widdows et al. 2015; Widdows and Downs 2015, 2016). Others use anthropogenic structures in the urban mosaic landscape, for example, southern tree agamas *Acanthocercus atricollis* that use brick walls, wooden fences, cement walls and various other human infrastructure for basking and refuge (Singh et al. 2021).

In urban mosaic landscapes, anthropogenic infrastructure often encroaches on natural environments, leading to their degradation and fragmentation, affecting various species. Despite this, various raptor species, like the Peregrine Falcon (*Falco peregrinus*) and Lanner

Falcon (*Falco biarmicus*), the Blacked-winged Kite (*Elanus caeruleus*), Common Buzzard (*Buteo vulpinus*), Black Sparrowhawk (*Accipiter melanoleucus*), African Fish Eagle (*Haliaeetus vocifer*), and African Crowned Eagles (*Stephanoaetus coronatus*), coexist to an extent with humans in urban mosaic landscapes (Turok and Borel-Saladin 2014; Venu 2018; McPherson et al. 2021; Table 1.1). With regard to biotic communities, urban built areas, in which humans and their activities dominate, generally result in changes in the arrangement of assemblages (Odewumi et al. 2020). Urban built areas can lead to urban built tolerant species being widespread (Łopucki et al. 2019; Odewumi et al. 2020).

Globally, the increased shift to urban living has increased interest in the effects that changes in land use have on bird communities as a direct result of human population growth and the growth rate of urban-built areas in urban mosaic landscapes (Lee et al. 2021). There remain gaps in knowledge and research regarding birds of prey communities in urban built areas despite their conservation importance and vulnerability to environmental disturbance (Odewumi et al. 2020). Urban-built areas in urban mosaic landscapes can promote a higher diversity or abundance of avian and rodent species, which are urban-built exploiters, resulting in prey availability for many raptor species (Faeth et al. 2011; Reynolds et al. 2019; Odewumi et al. 2020; McPherson et al. 2021). Generally, urban built areas have high densities of birds and rodents, resulting in increased biomass for prey selection for raptors that can be found close to their urbanised nesting sites (Odewumi et al. 2020). This may lead to certain raptor species seeking out urban-built environments as habitat and nest sites as this becomes beneficial hunting sites with the accumulation of not only avian prey but other species, such as rodents, in urban-built areas of urban mosaic landscapes (Reynolds et al. 2019; Sumasgutner et al. 2020). These prey species in urban built areas tend to experience lower population fluctuations than those in natural habitats (Sumasgutner et al. 2020). Birds are affected by urban built areas indirectly through disease, interspecific competition, and

predation, and directly because of changes in habitats, ecosystem processes, and available food supply (Odewumi et al. 2020).

Table 1.1: A summary of falcons found persisting in urban areas in South Africa.

Scientific name	Common name	Reference
Falco amurensis	Amur Falcon	(McPherson et al. 2021)
Falco biarmicus	Lanner Falcon	(Jenkins 1994; 2000a; 2000b; McPherson et al. 2021)
Falco peregrinus	Peregrine Falcon	(Jenkins 1994, 2000a, 2000b; Jenkins and Benn 1998; Altwegg et al. 2014; Sumasgutner et al. 2020; McPherson et al. 2021)
Falco naumanni	Lesser Kestrel	(McPherson et al. 2021)
Falco rupicoloides	Greater Kestrel	(McPherson et al. 2021)
Falco rupicolus	Rock Kestrel	(Jenkins and van Zyl 2005; McPherson et al. 2021)
Falco subbuteo	Eurasian Hobby	(McPherson et al. 2021)
Falco vespertinus	Red-footed Falcon	(McPherson et al. 2021)
Polihierax semitorquatus	Pygmy Falcon	(McPherson et al. 2021)

1.2 Falcons

Birds of prey, or raptors, refers to a classification of birds adapted to a lifestyle of ariel hunting and includes hawks, eagles, vultures, falcons, and ospreys (Elafri et al. 2020). Raptors are keystone species that belong to the Orders Falconiformes and Strigiformes (Venu 2018). Raptors are relatively large bird species encompassing a variable assortment of high-level predators that play a vital role in the proper functioning of ecosystems and have been growing in their conservational concern (Sarà et al. 2022). Raptors are one of the world's most threatened taxa, with approximately 52% of their populations declining globally and approximately 18% of raptor species being threatened with extinction (Granati et al. 2021).

Birds of prey can be distinguished by their flight style and conformation, with falcons having long wings, sparrowhawks having short wings, or eagles and buzzards having broad wings (Hart et al. 2018). Falcons have a high aspect ratio with narrow and long wings (Hart et al. 2018). Falcons' wings have become specialised to increase their flight speeds and to

become more efficient at hunting in open spaces (Hart et al. 2018; Sarà et al. 2022). Falcons typically pursue prey at high speeds and primarily hunt other birds but can target small mammals, reptiles, and insects (Hart et al. 2018; Elafri et al. 2020). Falcons encompass a diverse range of birds that hold cultural and economic significance and are one of the most successful groups of birds with an unmatched geographic distribution (Wilcox et al. 2022). Falcons have a long, rich, and complex history of association with humans, particularly with regard to falconry (Wilcox et al. 2022).

Raptors play an important role in the environments and can also be observed as bioindicators to offer a sign of the health of their habitats depending on their level of presence and, in some cases, diet preference (Granati et al. 2021). Falcons and raptors, in general, often have dispersed territories/distributions and can be secretive species by nesting in lower densities with less competition, making monitoring their population status difficult (Elafri et al. 2020). Falcons are a species that are biologically important, serving an ecological role in maintaining rodents and other small mammal populations, and are environmentally sensitive, allowing them to be indicators of the ecological health of the environments they reside in (Elafri et al. 2020). Falcons will almost exclusively be predatory, and their diets will all include birds to varying degrees of prey selection in their diet (Schoenjahn et al. 2022). The extent of bird selection in their diet will depend upon opportunities, season, prey availability, and competition (Granati et al. 2021; Schoenjahn et al. 2022). Some raptors can be generalist predators (such as the Lanner Falcon) and switch between available species of prey in their hunting territories or specialists selecting a single or a few prey types (Dawson et al. 2011). Specialised raptors' success will depend upon the availability of their selected or preferred prey species, while generalists can switch between available prey and are more likely to thrive in urban built areas (Dawson et al. 2011).

The Falconidae family forms a monophyletic group; however, the Peregrine Falcon and Lanner Falcon share morphological similarities with regard to their anatomical hunting traits without being sister species (Sarà et al. 2016). Body masses of falcons depend on a range of factors, such as extrinsic factors like parasite load and food availability and/or intrinsic factors like sex and age (Lee et al. 2020).

The Peregrine Falcon and Lanner Falcon are small to medium-sized birds that are widely distributed throughout sub-Saharan Africa and share similar habitat and nest requirements (Jenkins and Avery 1999). The two falcons differ in most measurements with regard to their wingspan, bill sizes, wing area, and tail length, which affects their performance and behaviour (Jenkins and Avery 1999). Adult Peregrine Falcons are ~ 34-43 cm in height, similarly adult Lanner Falcons are 36-48 cm in height, both species weigh ~600-1200 g, displaying a type of sexual dimorphism with females weighing more than males (Jenkins 1995; White et al. 2002; Hockey et al. 2005; White et al. 2020).

Falcons have a narrower and more pointed wing with a more energetically expensive flight (Mills et al. 2018). They can move fast and manoeuvrable because they typically doing "air-to-air" hunting and not locating prey on the ground (Mills et al. 2018). Peregrine and Lanner Falcons differ in their flight performances, prey capture techniques, and handling techniques (Jenkins and Avery 1999). Regarding flight performance, Peregrine Falcons can fly faster in gliding and level-powered flights but incur greater fuel costs than Lanner Falcons in terms of the time of flight and the distance flown (Jenkins and Avery 1999). Lanner Falcons can glide more efficiently and actively soar into and use thermals to reduce fuel costs (Jenkins and Avery 1999). In comparison, the Peregrine Falcon can fly faster; however, it can do so for less time, flap its wings more, and make less use of thermals than Lanner Falcons (Jenkins and Avery 1999). These falcons typically prefer to select nest sites on cliffs and will primarily feed on birds that are caught in aerial chases (Jenkins and Avery 1999). Both these falcons

can live sympatrically in semi-arid habitats, but both falcon species typically select nest sites on cliffs, require open spaces for hunting, and display territory behaviour (Sarà et al. 2016). In southern Africa, these two falcons occur sympatrically in many areas, with the Lanner Falcon being a more generalist feeder and having fewer requirements for nest site selection (Jenkins and Avery 1999). Resources available in urban built areas will alter the level of competition of these falcons depending on factors such as levels of human disturbance, falcon body sizes, the harshness of the gradients of that area, and even the abundance of prey species located there (Sarà et al. 2016). The Peregrine Falcon will primarily feed on birds caught in aerial pursuits, and the Lanner Falcon will feed on birds caught in aerial pursuits but also feed on a varying frequency of insects, reptiles, and small mammals (depending on availability) (Sarà et al. 2016). Niche theory predicts that the coexistence of these two falcon species is made possible because of morphological, behavioural, or ecological differences to minimise competition (Sarà et al. 2016). In South Africa, Lanner Falcon and Peregrine Falcons were found to use similar nesting habitat sites, but Lanner Falcons were more likely to use covered ledges or sheer faces with nearby cultivated lands, while Peregrine Falcons preferred shallower scree slopes with a variable vegetative structure nearby (Stephenson 2001).

1.3 Peregrine Falcon

The Peregrine Falcon (Family Falconidae, Order Falconiformes) is the most widely distributed bird of prey (López-López et al. 2009; Venu 2018; Mills et al. 2019; Tsaturyan et al. 2022). They are found in almost all regions of the earth except Antarctica. The Peregrine Falcon is a cosmopolitan bird species with a breeding range that covers approximately 40% of the world's land surface (Meyburg et al. 2018, Figure 1.1). There are ~75 subspecies of the Peregrine Falcon globally, with only ~16-19 of those being recognised (White et al. 2013; Bell 2015; Wink 2018). *Falco peregrinus minor*, a nonmigratory subspecies was the only

subspecies to have been found mentioned South Africa when conducting this research (Pepler et al. 1991; Jenkins 200b). The Peregrine Falcon is an opportunistic feeder and will select prey species based on what is available in their hunting territories, which will vary between habitats and seasons (Mills et al. 2019). African Peregrines prefer avian prey and will almost exclusively hunt birds, with a preference for pigeons and doves (Simmons et al. 2008). These falcons are considered opportunistic generalists and can feed on mammals, reptiles, insects, and fish but primarily prefer avian prey, using diverse foraging methods and achieving high levels of success in their foraging behaviours (Stevens et al. 2009). They can hunt various avian prey sizes using a range of unique attack and hunting strategies (Mills et al. 2019). These falcons will typically hunt birds smaller in size (such as pigeons, songbirds, ducks, and shorebirds), but are not limited to these birds (Stevens et al. 2009). This falcon has become increasingly urbanised, persisting in urban-built environments; however, little is known about their habitat use and selection in urban-built areas (Mak et al. 2021). Peregrine Falcons typically use nest sites that are advantageous for hunting, near waterbodies, green spaces (gardens and parks), and buildings (Mak et al. 2021). They select nest sites with topography that are advantageous for hunting in a close enough vicinity to their nesting sites, which are tall buildings in urban built areas that have a close preferred foraging/hunting location (Mak et al. 2021). Peregrine Falcons in North America typically have large territories and home ranges (ranging between 358-1508 km^2, overlapping home territories were greater than 28 km away), with a preference for topographically complex terrains that limit observational opportunities for their foraging and hunting behaviours (Craig 1997; Stevens et al. 2009). Natural habitats for this falcon include rock ledges, the sides of steep cliffs, caves, elevated crevices, coastal beaches, and cliffsides near bodies of water (Venu 2018). The Peregrine Falcon has a patchy distribution and prefers to occupy cliffs and rocky habitats that are typically near a vast open area or by a water source (Razafimanjato et al. 2007).

The Peregrine Falcon is listed as the Least Concern within the IUCN Red List of Threatened species (BirdLife International 2021a; Tsaturyan et al. 2022). Peregrine Falcons exhibit sexual dimorphism, commonly seen in many other raptors, where female Peregrine Falcons are ~50% heavier than males (Mills et al. 2019). This difference in size is believed to accommodate a wider variety of prey for breeding pairs of falcons. This enables them to exploit a wider range of prey through the division of labour, with the males being able to hunt for more manoeuvrable prey species while the females can carry larger prey sizes (Mills et al. 2019). Peregrine Falcons in Africa will mainly breed in spring during August-December but can breed later at higher latitudes (Simmons et al. 2008).

Unlike other species of birds, there is no colour difference between male and female Peregrine Falcons (Olsent and Cockburn 1991; Mills et al. 2019, Figure 1.2). However, as mentioned, the female is much larger than the male (males weigh ~600 g while females ~1.5 kg) (Olsent and Cockburn 1991). Peregrine Falcons are the fastest recorded bird worldwide and can reach speeds of 390 kms/h but have a typical flight speed of 320 km/h (Ponitz et al. 2014). The horizontal speed of the Peregrine Falcon, however, can only reach ~100 kms/h (Tucker et al. 2000; Ponitz et al. 2014). These falcons have narrower and more compact wings with tapered shapes, which reduces the turbulence the birds experience, which would be fatal at the high speeds they reach (Tucker et al. 2000; Ponitz et al. 2014).

Generally, falcons are skillful and calculating predators. Peregrine Falcons are most active in the morning and evening. They can look for prey from a high perch or fly closer to the ground to avoid attracting attention. They have specialised eyes that allow them to home in on prey from as far as 1 km away (Tucker et al. 2000; Mills et al. 2018). They prefer open spaces for hunting grounds and use hunting methods such as the stoop, which entails the falcon soaring to high altitudes before descending at great speeds to hunt prey mid-air (Mills et al. 2019). They reach such high speeds that they can result in air rushing into their lungs at

these high speeds, which could cause serious lung damage or even destroy their lungs (Ponitz et al. 2014; Mills et al. 2018). These falcons have specialised nostrils equipped with partitions that guide powerful airflows from them, thus protecting their lungs from the damage they would incur at high speeds (Mills et al. 2018). Peregrines are heavier than a bird of that size, but this is because of the terminal velocity that they reach, and the additional mass aids in "air-to-air" hunting (Tucker et al. 2000). Peregrine Falcons have strong, powerful legs and relatively sharp talons that are effective at catching prey, but at high speeds, it can result in the falcon's claws ripping through the length of the prey's entire body (Zhan et al. 2013; Mills et al. 2019). They have even been known to use their curved beak to break the neck of their prey (Zhan et al. 2013). In urban built areas, the Peregrine Falcon's main diet is pigeons (Dixon and Drewitt 2018). They may pursue a pigeon by chasing the bird using its horizontal flight speed or rapid stooping or dive-bombing prey (Tucker et al. 2000; Zhan et al. 2013; Mills et al. 2019).

In the mid-20th century, the Peregrine Falcon faced a dramatic decline in its population because of the effects of a pesticide used in forestry and agriculture (Tsaturyan et al. 2022). This bird of prey is especially vulnerable to pollution caused by pesticides, pollution from the mining industry, municipal dumpsites, and illegal falconry trading (Tsaturyan et al. 2022). The pesticide dichlorodiphenyltrichloroethane (DDT) nearly caused the Peregrine Falcons to go extinct. DDT had a variable effect on different birds (Olsen et al. 1992; Ydenberg et al. 2017). DDT was used as an insecticide, and the Peregrine Falcons may not eat a lot of insects, but their diet consists of animals that consume insects (Ydenberg et al. 2017). Due to biomagnification, the falcons could end up with a lot of the chemicals in their system (Brown et al. 2007). These effects did not seem to affect the adult birds, but they did cause the weakening of their eggshells (Falk et al. 2006; Ydenberg et al. 2017). This led to the eggs cracking or collapsing before they could hatch (Falk et al. 2006). Due to this, there was a

drastic reduction in the recruitment of new Peregrine Falcons for approximately 30 years while DDT was being heavily used (Olsen et al. 1992). Once the effects of DDT were discovered, they were banned but are still used in high malaria areas because it is a very effective insecticide (Brown et al. 2007; Wolmarans et al. 2021). Birds of prey like the Peregrine Falcon have been rescued from the brink of extinction because of the heavy reduction of the use of DDT and related chemicals (Brown et al. 2007; Castagna et al. 2024).

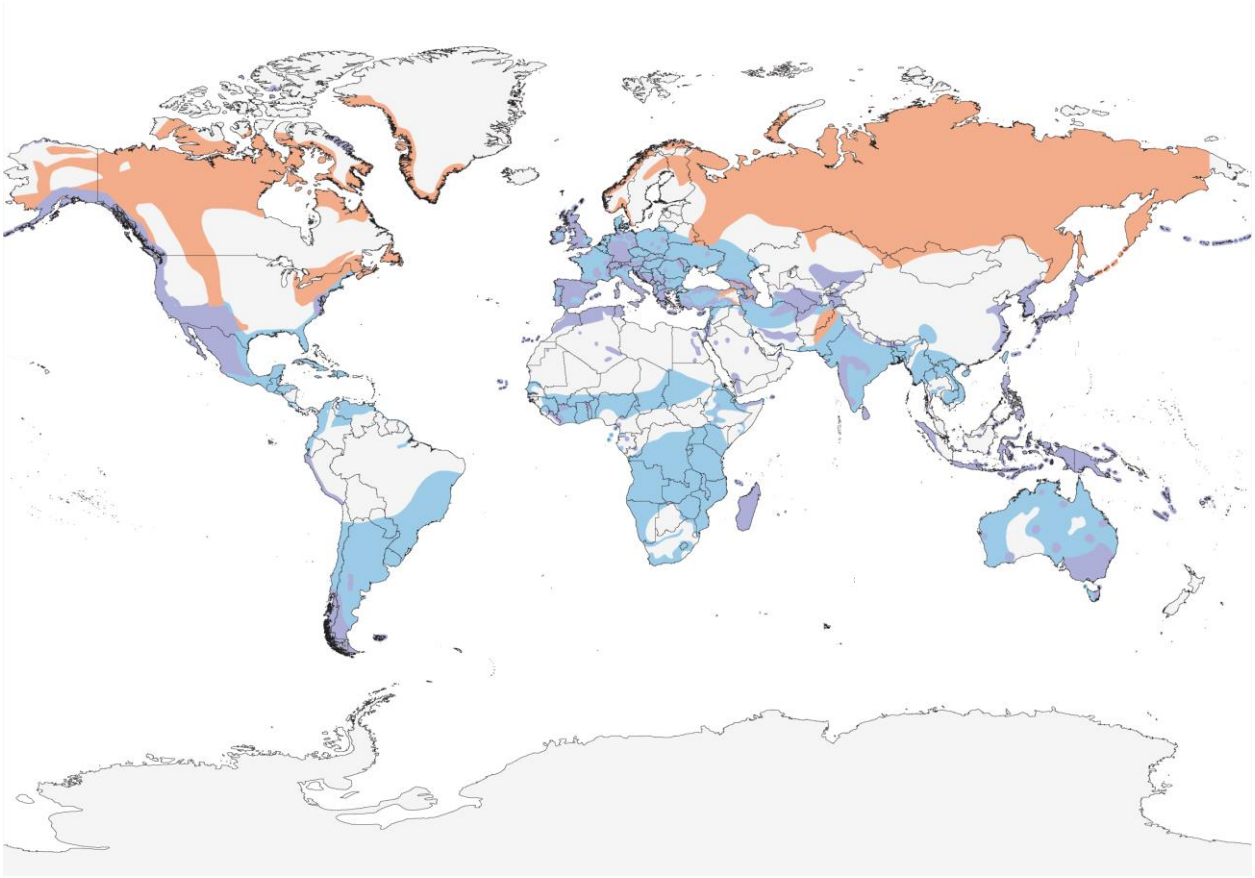

Figure 1.1: Map showing the Peregrine Falcon distribution range globally (area shaded in light purple represents the falcons' year-round distribution, yellow represents their migration, orange represents their breeding, and blue represents their non-breeding distribution) (Source: Birds of the World (White et al. 2020) (accessed: 02/10/2024)).

Figure 1.2: Adult Peregrine Falcon (Photo credit: Kyle Govender).

1.4 Lanner Falcon

The Lanner Falcon *Falco biarmicus* subspecies *feldeggii* is considered an Afrotropical species that displays behavioural plasticity (Grubač and Velevski 2010; Al Zoubi et al. 2019; Amato et al. 2021). The Lanner Falcon is listed as the Least Concern within the IUCN Red List of Threatened species (BirdLife International 2021b). There are limited mentions of the subspecies of Lanner Falcon, and no mention had been found from South Africa, however

Falco biarmicus feldeggii was notable among a few subspecies, particularly in Italy (Leonardi et al. 2013; Di Vittorio et al. 2017). Lanner Falcons are high-flying birds located in warm parts worldwide, like Africa, southern Europe, and the Middle East (Andreotti et al. 2008; Sarà 2014; Leonardi and Sutton 2020; Figure 1.3). Lanner Falcons are an Old World falcon species with a wide range all over Africa with varying degrees, except for the equatorial region (Andreotti et al. 2008; Al Zoubi et al. 2019). The Lanner Falcon is considered a shy species that is inconspicuous and not nearly as loud as other falcons like the Peregrine Falcon (Leonardi et al. 2013). Lanner Falcons are medium to large-sized successful predators with a broad chest, a beak with a notch, long, narrow, pointed wings, a relatively long tail, and a strong mallard stripe (Sarà 2014; Corso et al. 2017). Their colouration usually has a reddish pink chest with spot markings or a white chest with black speckling (Corso et al. 2017, Figure 1.4). They prefer warm and dry environments in the Mediterranean (Di Vittorio 2017). Lanner Falcons are aerodynamic and can fly in tight spaces; they are also a more buoyant species of falcon, using thermal gradients to reach high altitudes, often using thermals that do not expel much energy (low energetic costs) (Jenkins 1995; Hart et al. 2018).

Lanner Falcon habitats include agricultural lands and patches of natural habitats comprising sclerophyllous vegetation and grasslands (Di Vittorio 2017). This falcon prefers steppe-like and pre-desert habitats, where it will target a variety of nocturnal and diurnal vertebrates (Andreotti et al. 2008; Sarà 2014). Lanner Falcon habitat selection preferences include pasturelands, abandoned fields, scrublands, and steppes (Andreotti et al. 2008; Grubač and Velevski 2010). Lanner Falcons occupy home ranges varying in size from 66 km^2 to 249 km^2 (Stephenson 2001).

Lanner Falcons are not at the top of the predatory falcon food chain, but they are generalists and can switch preferred prey species depending on the presence of other falcons. For example, they hunt for rodents if a larger falcon is present in the area hunting birds (they

can hunt up, i.e., birds or hunt down, i.e., rodents and insects) (Grubač and Velevski 2010). Their preferred target of prey is small to medium-sized birds like pigeons and domestic chickens (*Gallus gallus domesticus*) (in urban/rural areas) (Stephenson 2001). Peregrines will not hunt in desert areas, but Lanner Falcons will (typically hunt small lizards), which is advantageous for the lanner because they have overlapping territories (Yosef 1991; Leonardi 2001). Lanner Falcons also make use of the stoop to catch their prey.

They tend to remain with their partner year-round and may loosely hunt together. This is a type of cooperative hunting (Leonardi 1999). The Lanner Falcons will hunt mainly small birds and will work together on the same prey while repeatedly stooping (Leonardi 1999). The males typically attack and direct the prey toward the female, and the females usually pursue the larger prey (Leonardi 1999).

The availability of nests limits the Lanner Falcons as they do not build their own nests and will lay their eggs in natural habitats on bare ledges on scrapes and ranging cliff sizes but also make use of old vacant nests from other birds, and in urban built habitats, these falcons may use building ledges and structures, electricity pylons, and vacant available nests (Stephenson 2001; Grubač and Velevski 2010). Generally, Lanner Falcons select nest sites are out of reach of predators such as the vervet monkey (*Chlorocebus pygerythrus*), but these areas are often difficult for observers to monitor (Stephenson 2001). In Africa, Lanner Falcons' breeding season is from July to October (Stephenson 2001).

Lanner Falcons suffered a drastic population decline in the mid-20th century because of poisoning from DDT, human hunting, and falcon trapping for falconry practices (Brown et al. 2007; Di Vittorio 2017). Habitat loss, afforestation, intensification of agricultural practices, and changes to agricultural practices threaten Lanner Falcons, resulting in a reduction in hunting areas and available prey species (Di Vittorio 2017).

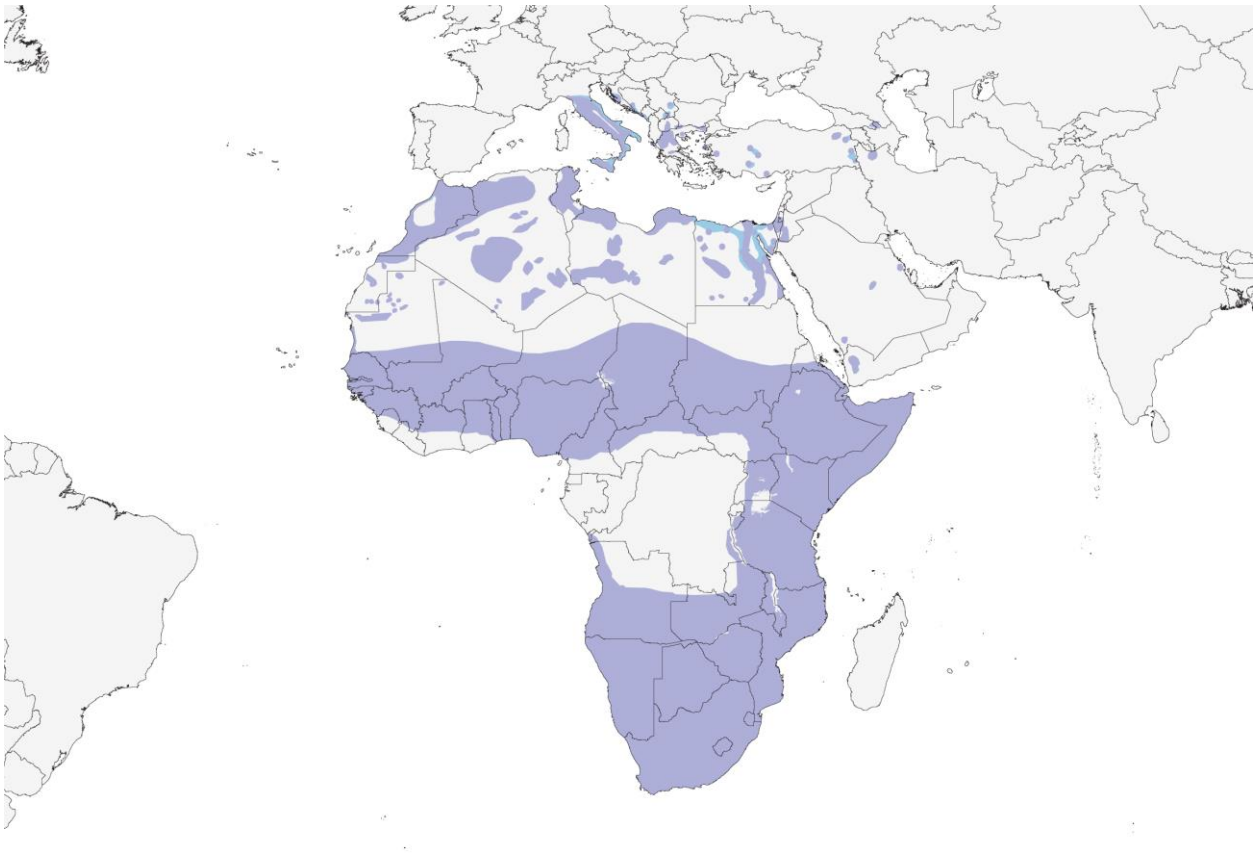

Figure 1.3: Map Showing the Lanner Falcon distribution range globally (area shaded in light purple represents the falcons' year-round distribution, yellow represents their migration, orange represents their breeding, and blue represents their non-breeding distribution) (Source: Birds of the World (Kemp and Marks 2020) (accessed: 02/10/2024)).

Figure 1.4: Adult Lanner Falcon (Photo credit: Kyle Govender).

1.5 Problem statement

Human populations and anthropogenic land use changes are increasing globally, having a negative effect on wildlife (McPherson et al. 2021). Urbanisation poses a major threat to biodiversity globally, resulting in natural environments transforming into mosaics of highly modified anthropogenic areas with remnants of green spaces (Muller et al. 2020; McPherson et al. 2021; Downs et al. 2021).

Tolerance to urbanisation varies among different avian species. Some species can adapt and exploit urban environments, whereas other more sensitive species will become urban avoiders and disappear entirely from these urbanised habitats. Raptors may be more sensitive to land-use changes compared with other avian taxa that occupy a lower trophic level (Muller et al. 2020). Many raptors, like the Peregrine Falcon and Lanner Falcon, persist and exploit urbanised habitats globally (Muller et al. 2020; McPherson et al. 2021). These falcons can co-occur in South Africa and exhibit complex dynamics influenced by their habitat and competition. Both falcons face threats from habitat degradation, land use changes, and competition. Competition is more documented in the Mediterranean, where the Peregrine Falcon has a tendency to displace and outcompete the Lanner Falcon at suitable breeding sites, compared with sub-Saharan species, which display negligible rates of aggressive interactions (De Rosa et al. 2015; De Rosa et al. 2019). The Peregrine Falcon and Lanner Falcon:

*Are medium to large falcons

*Have similar habitat and dietary requirements

*Can occupy the same habitats

*Are apex predators in arial pursuits

*Primarily feed on smaller bird species

*Are cliff-nesting species

Most raptor research in urban areas has been conducted in Europe and North America (the Global North) (Muller et al. 2020; McPherson et al. 2021). However, these findings may not necessarily represent other regions like South Africa, where conditions and variables may differ. While both falcons can adapt to urbanisation, the Lanner Falcon has a greater reliance on more natural habitats, whereas the Peregrine Falcon has been seen to thrive in urban environments globally. This highlights the need for more targeted conservation efforts that are specific to each falcon's preferred environments and to improve our understanding of

these falcons' interactions and distribution to mitigate competition that may occur between them.

1.6 Aims and objectives

I aimed to assess the distribution, presence, and persistence of two raptors, the Peregrine Falcon (*Falco peregrinus*) and the Lanner Falcon (*F. biarmicus*), across South Africa. Their co-occurrence and competition were assessed.

My objectives were as follows:

- To determine if urban built areas affect the persistence of Peregrine Falcons and Lanner Falcons.
- To determine the areas where the Peregrine Falcon and the Lanner Falcon co-occur in South Africa.
- To determine if the Peregrine Falcon outcompetes/displaces the Lanner Falcon in areas of co-occurrence.
- To determine if there are changes in historical home ranges/distribution of the falcons in South Africa.
- To make management recommendations for falcon persistence and feral pigeon removal.

1.7 Thesis structure

My thesis was prepared with the data chapters drafted as manuscripts for submission to international peer-reviewed journals. The hypotheses or predictions are presented in the respective chapters. This paper format leads to some unavoidable repetition. Chapter 1 is a brief introduction and includes my overall aims and objectives. Chapters 2, 3, and 4 are empirical data chapters, with each one covering a specific objective. Chapter 2 is a systematic

review examining published peer-reviewed literature globally on Peregrine Falcon and Lanner Falcon using Scopus®, PubMed®, Google Scholar® and Web of Science®. Systematic reviews are a type of systematic research that relies solely on a set of evidence-based methods that aim to minimise bias and maximise rigour (Haddaway et al. 2020). Chapter 3 examines the change between the historical and present distribution range of the Peregrine Falcon and Lanner Falcon across South Africa, including Lesotho and Eswatini, using the Southern African Bird Atlas Project (SABAP). Chapter 4 investigates images posted of the Peregrine Falcon and Lanner Falcon throughout South Africa on social media (iNaturalist®, Facebook®, and eBird®). Social media and networking platforms are growing in usefulness in research through citizen science contributions (Chowdhury et al. 2023). Chapter 5 (the final chapter) summarises the results and main findings from each of the previous chapters and provides future research recommendations.

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CHAPTER 2

A systematic review of Peregrine Falcon (*Falco peregrinus*) and Lanner Falcon (*Falco biarmicus*) research globally, and specifically in South Africa

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Running header: Systematic review of Peregrine and Lanner Falcon research

2.1 Abstract

Raptors are widely distributed globally and are under threat because of human activities. Our systematic review examined global literature on the Peregrine Falcon (*Falco peregrinus*) and Lanner Falcon (*F. biarmicus*) to highlight trends in research and gather insights on aspects that can be prioritised for future studies. Our systematic literature search found 1284 publications from the earliest year 1864 to the 31st of December 2024. There were more publications on Peregrine Falcons, which accounted for 92.5% (n = 1188) of the reviewed publications and 7.5% (n = 96) on Lanner Falcons. The literature reviewed on Peregrine Falcons was from Africa, Asia, Australia, Eurasia, Europe, North America, Oceania, and South America, while the literature reviewed on Lanner Falcons was from Africa, Asia, Europe, and North America. Research methods for studying Lanner Falcons primarily used observations/descriptive, biological, and genetic sampling and modelling for data collection. Similarly, the research methods used for Peregrine Falcons showed that observations/descriptive and biological and genetic sampling were the most frequently used for data collection. The leading research for Lanner Falcons covered breeding, health and environmental stressors, and habitat. The least covered research topics were genetics and taxonomy, interspecific interactions, intraspecific interactions, and movement. The main research topics for Peregrine Falcons were breeding, conservation, health and environmental stressors, and population ecology and demography. The least covered research topics were abundance, genetics and taxonomy, interspecific interactions, intraspecific interactions, and movement. Publications were heavily biased towards European and North American populations of Peregrine Falcons and towards European populations of Lanner Falcon, which aligns with both species' distribution ranges; however, more research is recommended to cover geographical regions of their distribution that remain understudied, particularly for Lanners.

Keywords: urban; falcon; research; raptors; species distribution; abundance trends; ecology

2.2. Introduction

The impacts of human activities on ecosystems are negatively impacting biodiversity (Madin et al. 2016; Wang et al. 2016). The continuous anthropogenic changing land use, especially urbanisation, and subsequent deterioration of natural environments increase strain on species dependent on native habitats and cause shifts in important interactions between co-occurring species (Lee et al. 2021; Pettersen 2022). Birds of prey, in particular, are among the most vulnerable taxa to environmental disturbances (Odewumi et al. 2020; Granati et al. 2021). Considering the conservation importance of birds of prey, and their vulnerability, little is known about the altering structuring of these bird communities because of urbanisation and human activities. Apart from being apex predators and key players in the food chains within the habitats in which they occur, raptors are important because they are bioindicators, demonstrating through their presence how healthy a particular ecosystem is (Granati et al. 2021). Human population growth, rapid urbanisation, and climate change, particularly in Africa, have increased interest in land-use changes' impact on bird communities (Jet et al. 2007; Lee et al. 2021).

Falcons are among the most successful species of birds, holding cultural and economic importance, and possess an unparalleled geographic distribution globally (Wilcox et al. 2022). Falcons are birds of prey from the genus *Falco* (Falconiformes) and are almost exclusively predatory raptors that include birds in their diet to varying extents (Wilcox et al. 2019; Schoenjahn et al. 2022). Falcons are broadly distributed in all continents except Antarctica (Wilcox et al. 2019). All members of the family *Falconidae* form a monophyletic group; although the Peregrine Falcon (*Falco peregrinus*) and Lanner Falcon (*Falco biarmicus*) are not sister species, they have a high morphological similarity with regards to their anatomically

derived specialisation for hunting (Sarà et al. 2016; Venu 2018). Raptors such as falcons often occur over large ranges at low densities, display elusive behaviour, and breed/nest in areas that are difficult to access (Donázar et al. 2016).

The Peregrine Falcon and Lanner Falcon are medium-sized raptors with similar basic habitat and food requirements, preferring to nest on cliffs and prefer avian prey (Jenkins and Avery 1999; Di Vittorio 2017; Venu 2018). The Lanner Falcon is a more generalised feeder with fewer habitat-specific requirements than the Peregrine Falcon, allowing Lanner Falcons to occupy a wider variety of habitats (Jenkins and Avery 1999). Peregrine Falcons are more opportunistic generalists preferring avian prey that are usually, but not always, smaller than themselves, and preferring habitats with more complex topographical terrains (sheer cliff habitats and canyons) that overlook woodlands and wetlands but have colonised other/various habitats around the world (Simmons et al. 2008; Stevens et al. 2009; Mills et al. 2019; Pettersen 2022). Both falcons, however, are primarily specialist bird hunters actively pursuing prey at high speeds in aerial assaults but will also hunt small reptiles and mammals, especially in drier habitats where preferred species are not as abundant (Hart et al. 2018). Peregrine Falcons will almost exclusively hunt avian prey, particularly pigeons and doves (Jenkins 1994; Simmons et al. 2008). These falcons determine their nest sites by features of landscape terrain and features such as slope, elevation, and orientation, as well as various factors, including competitors and site weather patterns (Amato et al. 2021; Mak et al. 2021). Both falcons have shown flexibility and adaptability through their increased use of urban areas, bridges, power stations, churches, and tall buildings for nesting (Jenkins 2000; Venu 2018; McPherson et al. 2021; Pettersen 2022).

Lanner Falcons are found across Africa, adjacent Mediterranean countries, and the Middle East, occupying warm and dry environments and agricultural land (Di Vittorio 2017; BirdLife International 2021a). Peregrine Falcons are the most widely distributed raptor

species and are considered a cosmopolitan species with a global distribution (López-López et al. 2009; Meyburg et al. 2018; Mills et al. 2019; BirdLife International 2021b). Both falcons are considered species of Least Concern according to the global IUCN assessments (BirdLife International 2021a, 2021b). Since both species of falcon prefer to nest on cliffs, prefer open habitats for hunting, and can inhabit urban areas, this can result in populations being sympatric (Sarà et al. 2016; Mills et al. 2019). Both falcons can and do occur sympatrically in sub-Saharan Africa, particularly southern Africa, but Lanner Falcons are more widely distributed (Jenkins 1995; Jenkins and Avery 1999; Jenkins 2000; SABAP2 2025). Lanner Falcons are generally considered a more shy and less vocal species than Peregrine Falcons (Leonardi et al. 2013). The similarities in habitat requirements, prey preferences, and morphological similarities would drive the potential interference between coexisting populations of these falcon species (Sarà et al. 2014).

This systematic literature review of the Peregrine Falcon and the Lanner Falcon was conducted to understand the state of global research for these falcons, to understand where research has been undertaken, and to provide insight on where research can/should be prioritised to improve conservation outcomes and status assignments for these falcons and their habitats. We expected publications on these falcons globally to have increased over time, primarily driven by bias toward these falcons' populations found in Europe and North America. We expected Peregrine Falcons to be the most studied because they are more widely distributed globally than Lanner Falcons. Our research aimed to highlight important species-specific gaps in scientific knowledge that will help improve research and Red List status assignments on these falcons moving forward.

2.3 Methods

We used Publish or Perish to source publications from Google Scholar®, Web of Science®, PubMed®, and Scopus® databases, and manual searches on Google Scholar® and Web of Science® were used to cross-reference. Papers were consolidated until the 31st of December 2024. We chose not to limit our searches by using a start date. Published literature was searched using Publish or Perish (Harzing 2022; https://harzing.com/researouces/publish-or-perish), Google Scholar® (https://scholar.google.co.za), Web of Science® (https://www.webofscience.com), PubMed® (https://pubmed.ncbi.nlm.nih.gov), and Scopus® (https://www.scopus.com) databases. We searched titles, text, and abstracts using the scientific and common names of both falcon species (e.g., "Peregrine Falcon", "*Falco peregrinus*", "*Falco biarmicus*", and "Lanner Falcon"). We followed a modified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and Reporting Standards for Systematic Evidence Syntheses (ROSES) (Haddaway et al. 2020; Canney et al. 2021).

Published literature (mainly peer-reviewed, primary research publications) that explicitly included either/both the Peregrine Falcon and Lanner Falcon in the study's title, abstract, methods, or results were included in the final dataset (Haddaway et al. 2015, 2020). Duplicated literature, non-English language publications (that could not be translated), books, and any publications in which the contents were not sufficiently accessible for data extraction were discarded. Publications that reported species inventories or multi-species analyses that reported species-specific information for either falcon were considered.

For each publication, the following were extracted: (i) the geographical location (region/country and continent) where the research was undertaken, (ii) the research discipline, (iii) the species of falcon (Peregrine/Lanner Falcon), (iv) methodological approach, (v) bibliographic information, and (vi) research environment (Table 2.1). All final publications

were categorised according to 14 general research areas that best summarised the variety of papers found, such as behaviour, breeding, and abundance of species (see Supplementary Information Table S2.1 and Table 2.1). More than one discipline could apply to a given paper because research disciplines were not mutually exclusive. The principal environment where each study was conducted was classified (were possible) according to four categories: urban, non-urban, both, or other.

Table 2.1: Extracted information from each publication for the purpose of the systematic review.

Variable	**Levels**
Bibliographic information	Year of publication and other general information for each record
Location	Continent and region/country in which the study was conducted
Research discipline	Abundance, behaviour, breeding, distribution, habitat, movement, diet and foraging, population ecology and demography, genetics and taxonomy, physiology and morphology, health and environmental stressors, interspecific interactions, intraspecific interactions, conservation
Research environment	Urban, non-urban, other
Methodological approach	Observational/Descriptive, Experimental, Modelling, Tracking and telemetry, Citizen Science, Acoustic techniques, Biological and genetic sampling
Species of falcon	Peregrine/Lanner Falcon

We categorised each study's predominant methodological approach as follows: (i) experimental, (ii) observational/descriptive, (iii) biological and genetic sampling, (iv)

modelling, (v) acoustic techniques, (vi) tracking and telemetry, and (vii) citizen science. The country or countries where each falcon study occurred was identified to assess the geographic distribution of research for both falcon species. The publication year of each study was used to assess temporal trends in research. Each publication was categorised into 14 topics based on the subject and methods used in each study to understand knowledge gaps better. We then used descriptive statistics using Microsoft Excel (Version 2411) to show trends in research.

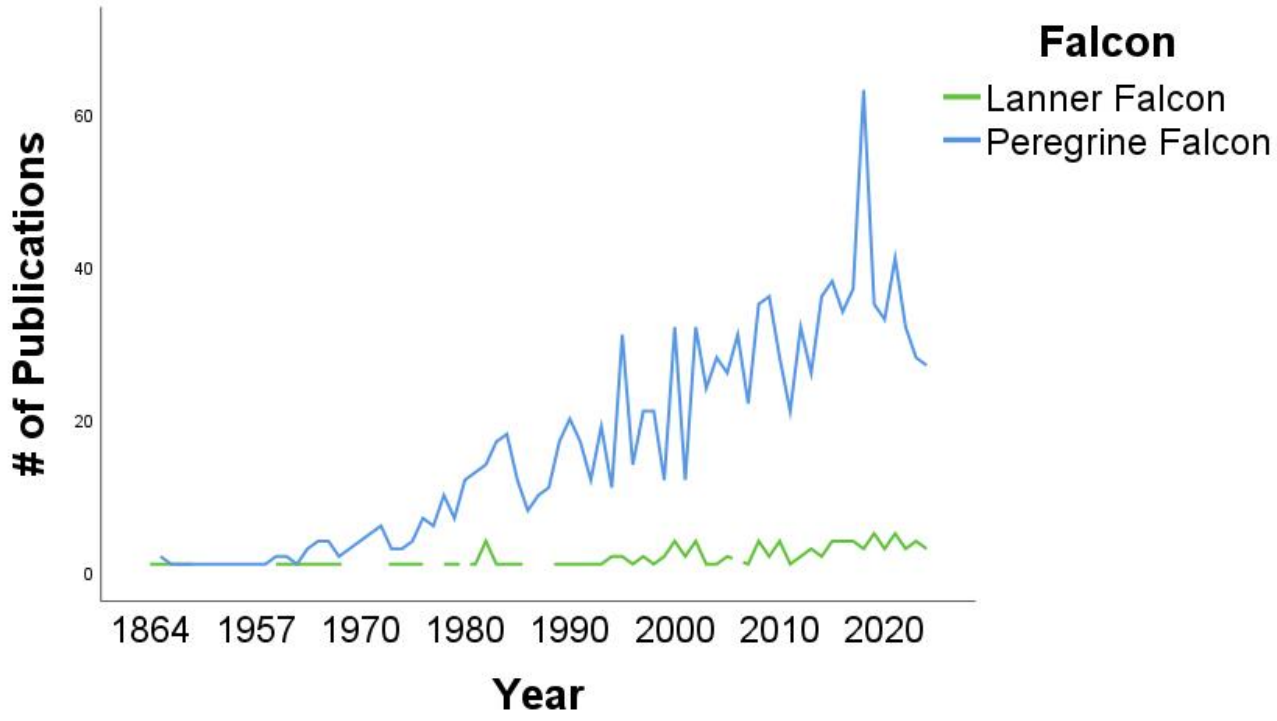


Figure 2.1: Annual trends in the number of publications on the Peregrine Falcon and the Lanner Falcon between January 1864 and December 2024.

2.4 Results

2.4.1 General trends

Our literature search on the Peregrine Falcon and Lanner Falcon produced a total of 1284 publications from 1864 (the earliest literature reviewed from our searches) to the 31st of

December 2024 (Figure 2.1; Figure 2.2, Supplementary Information Table S2.1). There were significantly more publications on the Peregrine Falcon, which accounted for 92.5% of the publications reviewed (Chi^2 test: $X^2 = 165.97$, df = 7, $P < 0.0001$). We examined 1188 publications on Peregrine Falcons and 96 (7.5%) publications on Lanner Falcons (Supplementary Information Table S2.1). From the Peregrine Falcon papers, 2.9% (n = 34) included and/or mentioned Lanner Falcons, and from the Lanner Falcons papers, 43.8% (n = 42) included and/or mentioned Peregrine Falcons. The literature on Peregrine Falcons was from Africa (n = 42, 3.6%), Asia (n = 98, 8.3%), Australia (n = 58, 4.9%), Eurasia (n = 12, 1.0%), Europe (n = 406, 34.2%), North America (n = 519, 43.7%), Oceania (n = 6, 0.5%), and South America (n = 47, 4.0%). In comparison, Lanner Falcons was from Africa (n = 28, 29.2%), Asia (n = 14, 14.6%), Europe (n = 51, 4.3%), and North America (n = 3, 0.3%). Consequently, from the reviewed published literature, publications were heavily biased towards Europe and North America for Peregrine Falcons, and Europe for Lanner Falcons (Figure 2.2; Table 2.2, Supplementary Information Table S2.1).

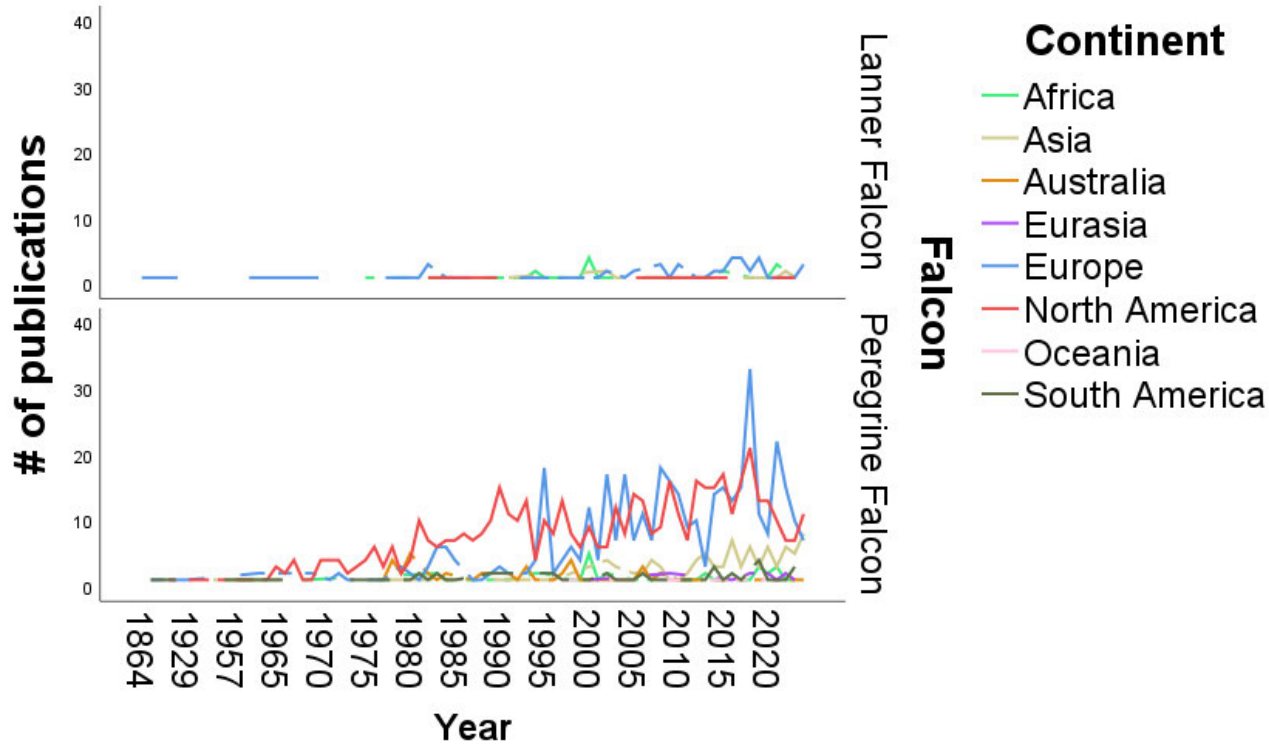


Figure 2.2: Annual trends in the number of publications on the Peregrine Falcon and Lanner Falcon per continent between January 1864 and December 2024.

Globally, published literature on Peregrine Falcons has increased over time. In contrast, Lanner Falcons appear to remain relatively understudied in comparison (Figure 2.1). The literature for Lanner Falcons from Africa ranged from 1975 to 2023, with 57.1% of the literature published after 2000. In contrast, for Peregrine Falcons, literature ranged from 1968 to 2023, with 69.1% of the literature published after 2000 (Figure 2.2). Literature from Asia for Lanner Falcons ranged from 1991 to 2023, with 92.9% published after the year 2000. In contrast, for Peregrine Falcons, literature ranged from 1953 to 2024, with 88.8% published after 2000. Reviewed literature from Europe on Lanner Falcons ranged from 1864 to 2024, with 78% published after 2000, while for Peregrine Falcons, it ranged from 1873 to 2024, with 77.8% published after 2000. Additionally, Peregrine Falcons published literature covering Europe and Asia, which were categorised as Eurasia for the continent of

origin/publication. Reviewed literature published in Eurasia for Peregrine Falcons ranged from 2000 to 2023. Literature from North America on Lanner Falcons ranged from 1982 to 2023, with 66.7% published after 2000 (although limited to 2 out of 3 papers), and literature on Peregrine Falcons ranged from 1916 to 2024, with 56.1% published after 2000. Peregrine Falcons also had literature published in Australia, South America, and Oceania, whereas Lanner Falcons had no publications in these regions from searches conducted in this study. Reviewed literature on Peregrine Falcons from Australia ranged from 1977 to 2024, with 36.2% published after the year 2000; those from South America ranged from 1873 to 2023, with 61.7% published after the year 2000, and those from Oceania ranged from 1997 to 2020, with 83.3% published after the year 2000 (although limited to 5 out of 6 papers).

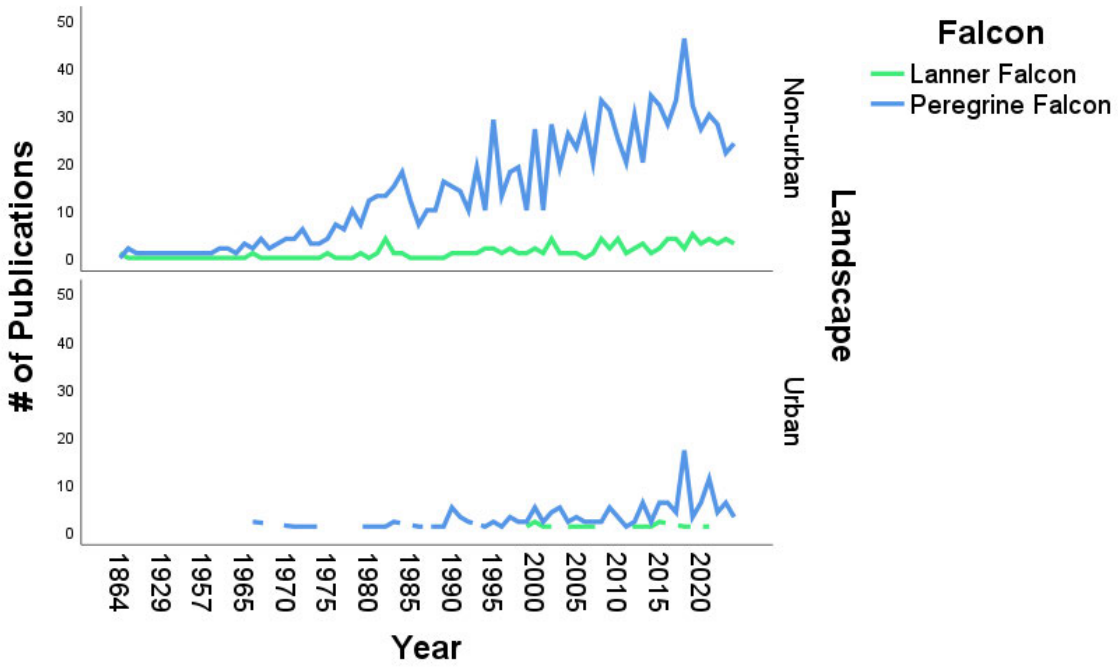


Figure 2.3: Annual trends in numbers of urban and non-urban landscape based research from publications on the Peregrine Falcon and Lanner Falcon between January 1864 and December 2024.

Globally, non-urban and urban (including urban landscapes) research on Peregrine Falcons has increased over time (Figure 2.3). For Peregrine Falcons, 88.0% (n =1045) were non-urban, and 12.0% (n = 143) were urban-based research. For non-urban research, 37.8% (n = 395) were before the year 2000, 30.1% (n = 314) were between 2001 and 2013, and 32.2% (n = 336) were between the years 2014 and 2024. For research that included urban landscapes, 24.5% (n = 35) were before the year 2000, 27.3% (n = 39) were between 2001 and 2013, and 48.3% (n = 69) were between the years 2014 and 2024.

In contrast, non-urban and urban (including urban landscapes) research showed that Lanner Falcons remain relatively understudied in comparison. For Lanner Falcons, 89.6% (n = 86) were non-urban, and 10.4% (n = 10) were urban-based research. For non-urban research, 30.2% (n = 26) were before the year 2000, 29.1% (n = 25) were between 2001 and 2013, and 40.7% (n = 35) were between the years 2014 and 2024. For research that included urban landscapes, 30.0% (n = 3) were before the year 2000, 20.0% (n = 2) were between 2001 and 2013, and 50.0% (n = 5) were between the years 2014 and 2024.

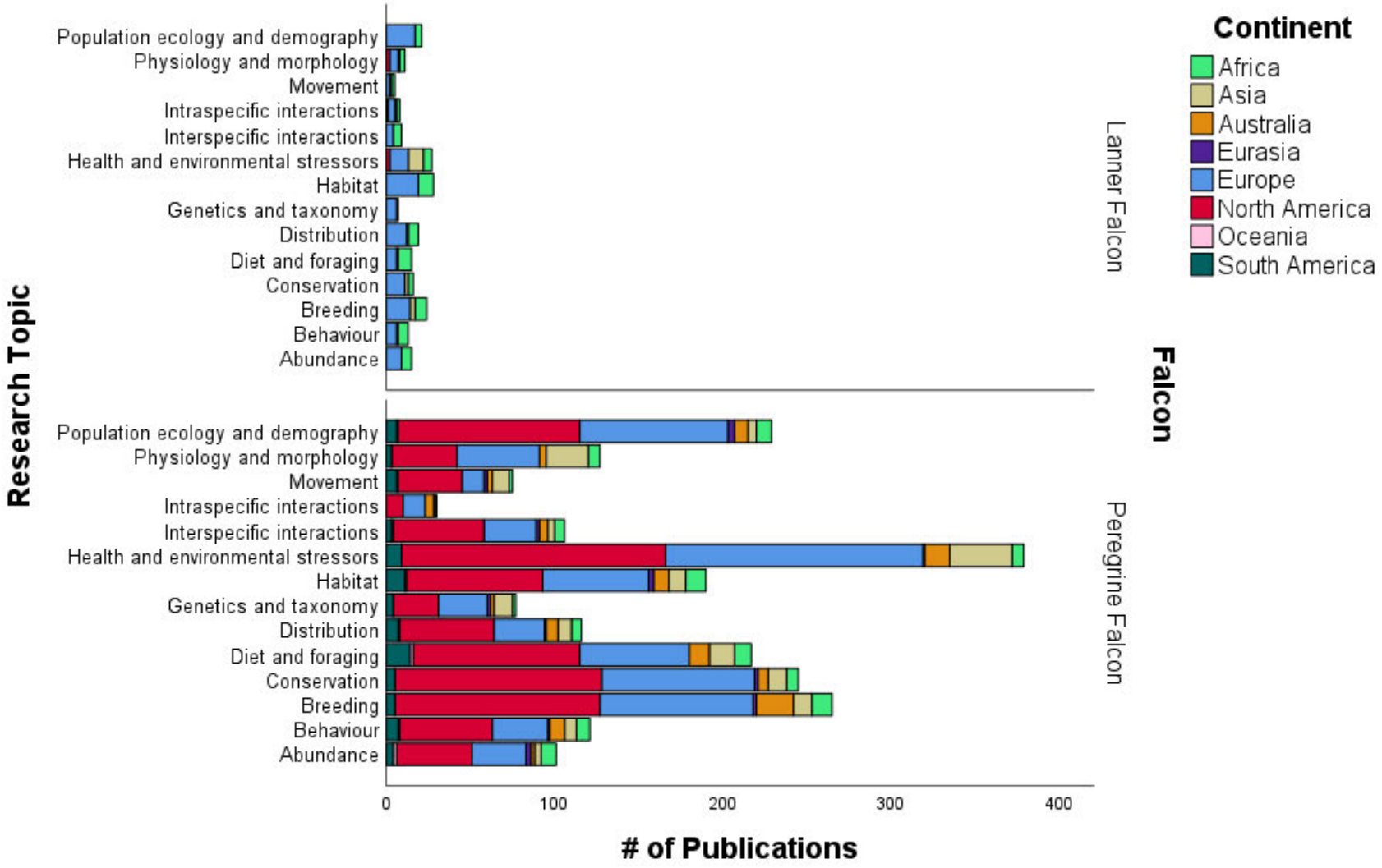
When comparing continent contributions from the reviewed literature, Europe contributed the most publications on Lanner Falcons, and the most on Peregrine Falcons were from North America, followed closely by Europe (Table 2.2). Research that was based in non-urban landscapes was from "non-urban" and "other", and research/literature that included urban landscapes was from "urban" and "both." Europe accounted for 53.1% of the reviewed literature on Lanner Falcons, with the research environment predominately taking place in non-urban based (92.2%) environments, and fewer studies included urban (7.8%) environments. Similar trends were seen for Peregrine Falcons. Europe accounted for 34.2% of the literature on Peregrine Falcons and was predominately in non-urban (87.4%) environments, with fewer studies including urban (12.6%) environments. North America

contributed the least number of publications on Lanner Falcons, only 3.1%, with all the research conducted in non-urban landscapes under the "other" category.

In contrast, North America contributed the highest number of publications on Peregrine Falcons, contributing 43.7% of reviewed publications, with most research conducted in non-urban (87.5%) environments and fewer studies included urban (12.5%) environments. Africa contributed the second-highest number of publications on Lanner Falcons, contributing 29.2% of the literature, with research predominately conducted in non-urban (78.6%) environments and few studies including urban (21.4%). Africa contributed to 3.5% of the literature on Peregrine Falcons, with most research (73.8%) conducted in non-urban environments and less research in urban (26.2%). Asia contributed 14.6% of the reviewed literature for Lanner Falcons, with the research conducted only in non-urban environments. Similarly, for Peregrine Falcons, Asia contributed 8.3% of the literature, with most (96.9%) in non-urban and a few studies (3.1%) including urban environments. Additionally, studies in Eurasia were only on Peregrine Falcons and contributed 1.0% of the literature reviewed. The studies under Eurasia were also considered independent of European and Asian studies, respectively. Research in Eurasia predominately was in non-urban (91.7%) environments, with only one study conducted in an urban setting (8.3%). Research conducted in South America, Australia, and Oceania only returned searches on literature published on Peregrine Falcons. Oceania contributed the least published literature on the Peregrine Falcon (0.5%), with the research only conducted in non-urban environments. South America contributed to 4.0% of the literature, with most (80.9%) published research conducted in non-urban environments and fewer studies (19.2%) including urban environments. Australia contributed to 4.9% of the literature on Peregrine Falcons, with the research environment primarily conducted in non-urban (94.8%) and some (5.2%), including urban environments.

Table 2.2: Summary of other geographic findings from reviewed publications on Peregrine Falcons and Lanner Falcons from 1864 to 2024.

	Landscape	**# of Falcon publications**	
Continent	**(Urban/non-urban)**	**Peregrine**	**Lanner**
Africa	Both	8	4
	Non-urban	23	17
	Other	8	5
	Urban	3	2
Asia	Both	2	0
	Non-urban	32	2
	Other	63	12
	Urban	1	0
Australia	Both	1	0
	Non-urban	42	0
	Other	13	0
	Urban	2	0
Eurasia	Both	0	0
	Non-urban	10	0
	Other	1	0
	Urban	1	0
Europe	Both	26	2
	Non-urban	154	24
	Other	201	23
	Urban	25	2
North America	Both	24	0
	Non-urban	302	0
	Other	152	3
	Urban	41	0
Oceania	Both	0	0
	Non-urban	6	0
	Other	0	0
	Urban	0	0
South America	Both	4	0
	Non-urban	26	0
	Other	12	0
	Urban	5	0



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2 **Figure 2.4:** Research topics covered from publications on Peregrine Falcons and Lanner Falcons globally from January 1864 to December 2024.

All 14 research topics were covered, with varying degrees, for both species of falcons in the literature (Figure 2.4). Published literature could cover multiple research topics/disciplines because research disciplines were not mutually exclusive. From the reviewed literature, Peregrine Falcon's research covered 2278 research types/disciplines and 218 for Lanner Falcons. The research covered on Lanner Falcons with >10% per topic covered (subsequently the main research topics of interest for the species) from the reviewed literature covered breeding (11.0%), habitat (12.8%), and health and environmental stressors (12.4%)(Figure 2.4). Research topics were then followed by 10%>x>5% per topic (subsequently the secondary research topics of interest for the species) covering abundance (6.9%), behaviour (6.0%), conservation (7.4%), diet and foraging (6.9%), distribution (8.7%), physiology and morphology (5.1%), and population ecology and demography (9.6%). The least covered research topics (<5% per topic covered) were genetics and taxonomy (3.2%), interspecific interactions (4.1%), intraspecific interactions (3.7%), and movement (2.3%).

The research topics for the Peregrine Falcon with >10% of the reviewed literature (subsequently the main research topics for the species) were on breeding (11.6%), conservation (10.8%), health and environmental stressors (16.6%), and population ecology and demography (10.5%) (Figure 2.4). Secondary research topics of interest that covered 10%>x>5% per topic were on behaviour (5.3%), diet and foraging (9.5%), distribution (5.1%), habitat (8.3%), and physiology and morphology (5.6%). The least covered research topics were <5% per topic covering the reviewed literature were on abundance (4.4%), genetics and taxonomy (3.4%), interspecific interactions (4.7%), intraspecific interactions (1.3%), and movement (3.3%).

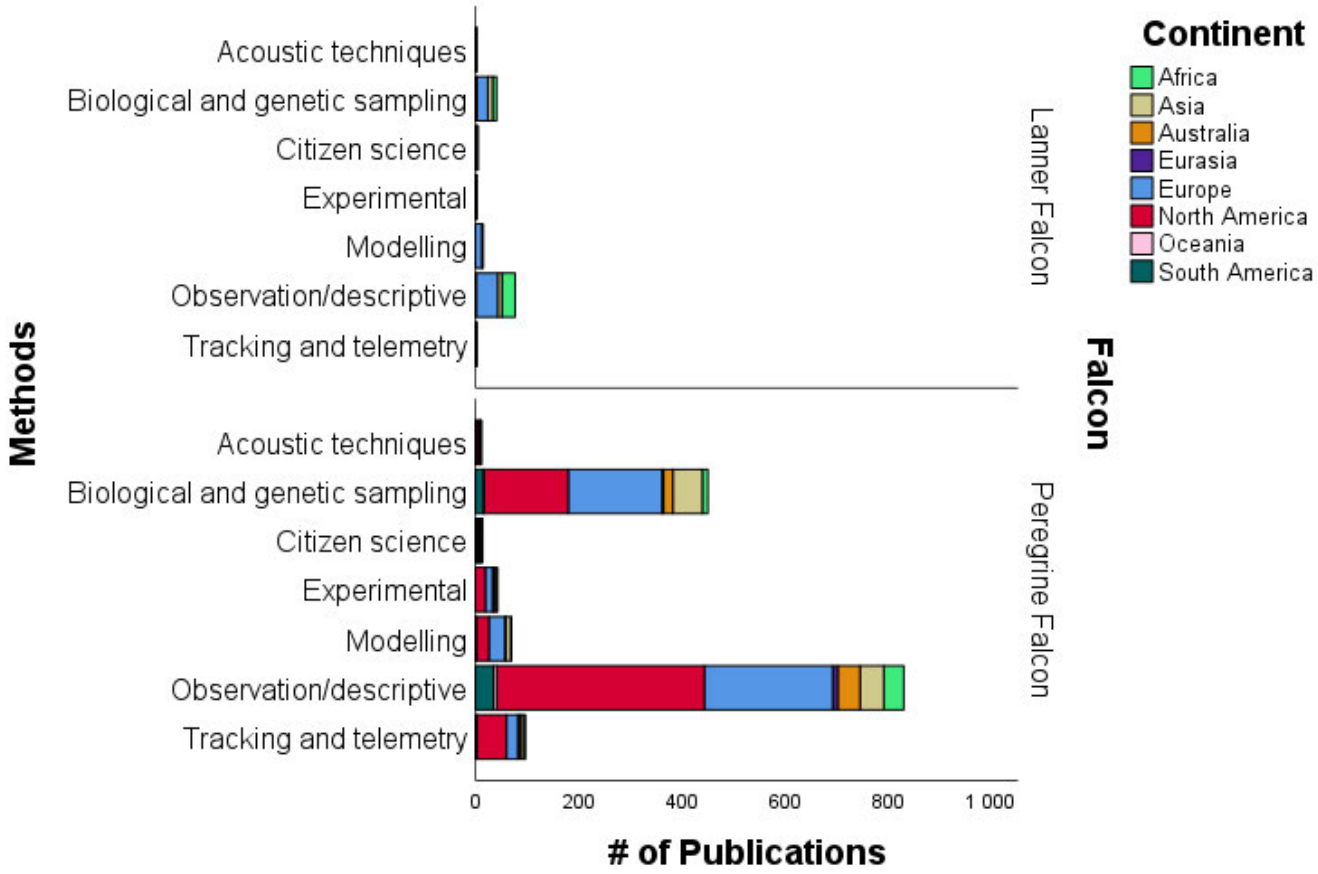

Figure 2.5: Selected method types used covered in publications on Peregrine Falcons and Lanner Falcons globally from January 1864 to December 2024.

From the reviewed publications, all seven method types were covered with varying degrees for both species of falcons (Figure 2.5). Published literature could cover multiple research methodologies depending on interest because research methods were not mutually exclusive. From the reviewed literature, Peregrine Falcon research covered 1517 methods, whereas only 146 were for Lanner Falcons. From the literature, the main research methods used for research on Lanner Falcons (>10% of reviewed literature for the species) were observations/descriptive (52.7%), biological and genetic sampling (28.1%), and modelling (10.3%) methods or techniques for data collection. The other four methods were not as

frequently used (<5% of reviewed literature for the species): citizen science (3.4%), tracking and telemetry (2.1%), experimental (2.1%), and acoustic techniques (1.4%) of methods used for data collection.

Similarly, the research methods used in the literature on Peregrine Falcons showed that observations/descriptive (54.8%) and biological and genetic sampling (29.7%) (>10% of reviewed literature for the species)methods or techniques were the most frequently used for data collection. Tracking and telemetry (6.4%) was the third most used method or technique for data collection (10%>x<5% of reviewed literature for the species). The other four methods were not frequently used (<5% of reviewed literature for the species): modelling (4.6%), experimental (2.8%), citizen science (0.9%), and acoustic techniques (0.7%) as methods used for data collection.

2.4.2 Highlighting trends in South Africa

There were 5.5% (n = 70) of the papers from Africa, and 57.1% (n = 40) of those from South Africa. According to the papers from South Africa, 65% (n = 26) were on Peregrine Falcons, and 35% (n = 14) were on Lanner Falcons. From the Peregrine Falcon papers, 42.3% (n = 11) included and/or mentioned Lanner Falcons, and from the Lanner Falcons papers, 57.1% (n = 8) included and/or mentioned Peregrine Falcons. For the Peregrine Falcon, 19.2% (n = 5) included an urban landscape, and 65.4% (n = 17) were in non-urban landscapes. For the Lanner Falcon, 35.7% (n = 5) included an urban landscape, and 64.3% (n = 9) were in non-urban landscapes.

From the reviewed literature from Africa, Peregrine Falcon's research covered 64 research types/disciplines and 39 for Lanner Falcons. Also, 13 research topics were covered for both falcons, and the research topic "genetics and taxonomy" was not covered for either

falcon in South Africa. The research topics for the Peregrine Falcon with >10% of the reviewed literature (subsequently the main research topics for the species) were on habitat (15.6%), breeding (14.1%), diet and foraging (10.9%), and abundance (10.9%). Secondary research topics of interest that covered 10%>x>5% per topic were on population ecology and demography (9.4%), behaviour (7.8%), physiology and morphology (7.8%), and interspecific interactions (6.3%). The least covered research topics were <5% per topic covering the reviewed literature were on distribution (4.7%), health and environmental stressors (4.7%), conservation (3.1%), movement (3.1%), and intraspecific interactions (1.6%).

The African research on Lanner Falcons with >10% per topic covered (subsequently the main research topics of interest for the species) from the reviewed literature covered breeding (15.4%), habitat (12.8%), abundance (10.3%), behaviour (10.3%), and distribution (10.3%). Research topics were then followed by 10%>x>5% per topic (subsequently the secondary research topics of interest for the species) covering interspecific interactions (7.7%), physiology and morphology (7.7%), population ecology and demography (7.7%), diet and foraging (5.1%), and intraspecific interactions (5.1%). The least covered research topics (<5% per topic covered) were conservation (2.6%), health and environmental stressors (2.6%), and movement (2.6%).

From the reviewed publications from South Africa, six method types were covered with varying degrees for both species of falcons. The research method of acoustic techniques was not used. From the reviewed literature, Peregrine Falcon's research covered 42 methods, and Lanner Falcons had 22. These research methods on Peregrine Falcons showed that observation/descriptive (59.5%) and biological and genetic sampling (14.3%) (>10% of reviewed literature for the species from South Africa) methods or techniques were the most frequently used for data collection. Secondary methods included citizen science (9.5%) and

tracking and telemetry (9.5%) used for data collection (10%>x<5% of reviewed literature for the species from South Africa). The other methods were not as frequently used and used experimental (4.8%) and modelling (2.4%) (<5% of reviewed literature for the species) methods or techniques for data collection. From the literature, in South Africa, the main research methods used for research on Lanner Falcons were observation/descriptive (63.6%) (>10% of reviewed literature for the species) methods or techniques for data collection. Secondary methods included biological and genetic sampling (9.1%), citizen science (9.1%), and tracking and telemetry (9.1%) (10%>x<5% of reviewed literature for the species from South Africa). The other methods were not as frequently used and included experimental (4.6%) and modelling (4.6%) (<5% of reviewed literature for the species) methods or techniques for data collection.

2.5 Discussion

The reviewed published literature from 1864 to 2024 showed more publications on Peregrine Falcons, which accounted for 92.5% of the publications reviewed, while the literature on Lanner Falcons only accounted for 7.5% of the publications reviewed. Peregrine Falcons are the most widely distributed cosmopolitan bird of prey found in almost all corners of the earth except Antarctica, with a breeding range that covers approximately 40% of the world's land surface (López-López et al. 2009; Meyburg et al. 2018; Venu 2018; Mills et al. 2019; Tsaturyan et al. 2022). This was reflected in the reviewed literature on Peregrine Falcons covering geographical areas from Africa, Asia, Australia, Eurasia, Europe, North America, Oceania, and South America. In contrast, Lanner Falcons are considered an Afrotropical species that are located in warmer parts worldwide, with a wide range all over Africa (except for the equatorial region), southern Europe, and the Middle East (Andreotti et al. 2008; Grubač

and Velevski 2010; Sarà 2014; Al Zoubi et al. 2019). This was reflected in Lanner Falcon literature covering geographical areas of Africa, Asia, Europe, and North America. Since Peregrine Falcons have a wider global distribution than Lanner Falcons, this may account for, to an extent, the difference between the quantity of literature published on both species of falcons. Publications were heavily biased towards European and North American populations of Peregrine Falcons and towards European populations of Lanner Falcons, accounting for the most publications for each species. In the context of Africa, Peregrine Falcons and Lanner Falcons share similar habitat and nest requirements and are widely distributed throughout sub-Saharan Africa, where they co-occur (Jenkins and Avery 1999). However, the published literature reviewed from Africa was predominantly on Peregrine Falcons. The same trend was found in the literature from Europe, North America and Asia. Compared with Peregrine Falcons, Lanner Falcons were poorly researched.

Both falcon species had some research in urban areas within their distributional ranges. All continents besides Oceania contributed to urban research on Peregrine Falcons. North America and Asia did not contribute any urban research on Lanner Falcons, with only Europe and Africa contributing. The trends in research show a growing interest in urban ecological studies for these falcon species, particularly from the last ten years. Urban ecology is a relatively new and dynamic field of research interest, with the complex relationship between wildlife and humans within urban mosaic landscapes remaining relatively understudied (Faeth et al. 2011; Soulsbury and White 2015). Urban landscapes are characterised by anthropogenic structures such as roads, buildings, and energy infrastructures (Zhang 2016; Maphalala et al. 2021). Urban landscapes are typically combinations of complex habitat mosaics, which include a mix of streets, buildings, paved surfaces, roads, and other infrastructures (which make up grey space) and the vegetation of the city (which make

up natural or managed green spaces) (Faeth et al. 2011; Magle et al. 2012; Soulsbury and White 2015; Downs et al. 2021).

The typical effects of urbanisation worldwide have generally led to the loss of natural habitats, habitat fragmentation, loss of indigenous species, urban stressors (such as noise, lights, and pollution), modification of natural cycles, and introduction of domestic pets that may act as predators or in some cases prey (Meffert and Dziock 2013; Odewumi et al. 2020; McPherson et al. 2021). This highlights the importance of urban-based research to better understand urbanisation's dynamics and effects on these falcon species and wildlife in general. Both species of falcons can be found in urban areas in their distributional ranges, and these urban-built areas also result in new opportunities, new ecological niches, and new nest sites that allow some species, like Peregrine Falcons and Lanner Falcons, to thrive and become urban exploiters (Kark et al. 2007; Lee et al. 2021). Additionally, several prey species of these falcons have become urban-built dwelling wildlife populations, such as sparrows, pigeons, starlings, rats, and small mammals, and these species take advantage of the relative abundance of food, shelter, and warmer temperatures, but also attribute to the success of birds of prey such as Peregrine Falcons and Lanner Falcons, within these urban areas (Faeth et al. 2011; Palacio 2020).

Our systematic review of published literature on both falcons showed that the research focus on Peregrine Falcons has grown in the past two decades and continues to rise with interest, while research on Lanner Falcons remains low and severely understudied in comparison. From the reviewed publications, all seven method types were covered with varying degrees for both species of falcons. The main research methods used for research on Lanner Falcons used observation/descriptive (e.g., surveys, fieldwork, census), biological and genetic sampling (e.g., DNA extraction, prey remain analysis, morphometrics), and modelling

(e.g., simulations, predictive models), techniques for data collection. The other four methods that were not as frequently used and are subsequently recommended to be used more in future studies to increase data collection are citizen science (e.g., Southern African Bird Atlas Project, questionnaires), tracking and telemetry (e.g., radio-tracking, banding), experimental, and acoustic techniques as methods for data collection.

Similarly, the research methods used in the literature on Peregrine Falcons showed that observation/descriptive and biological and genetic sampling methods or techniques were the most frequently used for data collection. Tracking and/ or telemetry was the third most used method or technique for data collection. The other four methods were not as frequently used and subsequently are recommended to increase future research: modelling, experimental, citizen science, and acoustic techniques as methods for data collection.

The literature's most researched topics on Lanner Falcons covered breeding, health and environmental stressors, and habitat. The least covered research topics and subsequent recommendations for future research to focus on were genetics and taxonomy, interspecific interactions, intraspecific interactions, and movement. The main research topics for Peregrine Falcons focussed on breeding, conservation, health and environmental stressors, and population ecology and demography. The least covered research topics and subsequent areas where future research can focus were abundance, genetics and taxonomy, interspecific interactions, intraspecific interactions, and movement. Research that directly contributes to the conservation of Peregrine Falcons was predominantly conducted in North America and Europe, and in Europe for Lanner Falcons. The research mainly focussed on monitoring and assessing environmental factors' effects on the falcons, but this research remains understudied.

South Africa accounted for a large proportion of the papers that were based in Africa. From those papers, Peregrine Falcons were more studied than Lanner Falcons, but both remain understudied in this region overall. A larger proportion of Lanner Falcon papers mentioned and/or included the Peregrine Falcon. This trend was more prevalent in South Africa. This shows that the Lanner Falcon is often grouped with the Peregrine Falcon for research, yet the Lanner Falcon remains understudied overall. Both species were studied in urban and non-urban landscapes, although non-urban-based research was more prevalent. Genetics and taxonomy were research topics lacking for a South African landscape, and future research can aim to mitigate this. Peregrine Falcon research from the reviewed literature in South Africa focussed mainly on their habitat, breeding, diet and foraging, and abundance. The least covered research topics and where research can be improved include their distribution, health and environmental stressors, conservation, movement, and intraspecific interactions. Similarly, the main research on Lanner Falcons from the reviewed literature covered their breeding, habitat, abundance, behaviour, and distribution, while the least covered research topics and where research can be improved include conservation, health and environmental stressors, and movement. Observational and descriptive method techniques were the most commonly used when studying these falcons, and experimental, modelling, and acoustic techniques were underutilised.

The focus of this systematic review on published literature from peer-reviewed publications left out literature by multi-chaptered dissertation research that covered more extensive research and varying methodologies, books, and any published literature that was not accessible or if the required data could not be extracted from the abstract along (where the abstract is available but not rest of the contents). Some of the returned literature titles from our searches on Publish or Perish were not accessible beyond the citation in some cases, and

thus, that literature was excluded. The program Publish or Perish did not produce results from all publications on the searched terms, and thus, manual searches were conducted to try to prevent/reduce biases based on searches on the programs used. Regardless, the 1284 published literature used in this study represents the majority of accessible research available for both falcons globally. Improved methods and more extensive searches, using more grey literature, more non-English publications (that could not be translated for this review), and contacting experts from relevant fields to provide literature from their stored resources/inventories (Haddaway et al. 2020; Canney et al. 2021) are suggested for a more comprehensive systematic review. As expected, publications on these falcons globally have increased over time, primarily driven by research conducted on these falcons' populations found in Europe and North America. The Peregrine Falcon was, in fact, the most studied.

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2.8 Supplementary Information

Supplementary Information Table S2.1. Summary of peer-reviewed publications on Peregrine Falcons and Lanner Falcons used in the present study.

https://docs.google.com/spreadsheets/d/1KJACteomaY-6jj6yXQJK1EBMCKDffZCXHblZ1bIt1cY/edit?usp=drive_link

CHAPTER 3

Urban persistence and species interactions: Diverging trends in the Peregrine Falcon and Lanner Falcon abundance across southern Africa using the Southern African Bird Atlas Project

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Running header: Presence and persistence of Peregrine and Lanner Falcons

3.1 Abstract

Citizen science has emerged as a powerful tool for engaging the public in collecting extensive ecological data, crucial for monitoring species distribution and abundance over large geographic scales and extended time periods. This study leverages data from the Southern African Bird Atlas Project (SABAP) to investigate the distribution and relative abundance of the Peregrine Falcon (*Falco peregrinus*) and Lanner Falcon *(Falco biarmicus*) across South Africa, Lesotho, and Eswatini. Both species, known for their adaptability to diverse environments, often coexist across sub-Saharan Africa, sharing similar habitat preferences and prey species. We analysed data from SABAP1 (1987–1992) to the ongoing SABAP2 (2007–2024) to detect changes in distribution patterns and abundance over time. Our results indicated a notable increase in Peregrine Falcon reporting rates, particularly in urban areas between SABAP1 and SABAP2, suggesting successful adaptation to anthropogenic landscapes where tall buildings provide suitable nesting sites. In contrast, the Lanner Falcon displayed a more varied pattern, with some regions showing declines, especially where Peregrine Falcons were more prevalent during SABAP2, potentially indicating competitive displacement mediated by urbanisation. These findings underscore the complex interplay between urbanisation, species competition, and habitat preferences in shaping these raptors' distribution and population trends. While the behavioural plasticity of the Peregrine Falcon to urban environments highlights its resilience, the mixed responses of the Lanner Falcon suggest targeted conservation strategies to mitigate the impacts of habitat fragmentation and urban encroachment. This study's use of the Southern African Bird Atlas Project data illustrates its value in long-term ecological monitoring and its potential for informing conservation efforts.

Keywords: Citizen science; raptors; species distribution; abundance trends; urban ecology; conservation

3.2 Introduction

Southern Africa is experiencing rapid human population growth and urban expansion, resulting in pressure on wildlife with anthropogenic land transformation leading to habitat loss, fragmentation, species invasion, and pollution (McPherson et al. 2021; Leveau and Ibáñez 2022). Urbanisation is particularly influential, leading to irreversible landscape changes that generally negatively impact biodiversity (Kettel et al. 2019; Sakketa 2023). However, for some species, urban areas present new opportunities, including supplementary food sources, reduced predation pressure, and the availability of anthropogenic structures for nesting or denning (Altwegg et al. 2014; Winarni et al. 2022; Chen et al. 2023; Sanetra et al. 2024).

The Peregrine Falcon (*Falco peregrinus*) and Lanner Falcon (*Falco biarmicus)* are small to medium in size, with similar habitat preferences (nesting on cliffs) and food requirements (preferring to feed on smaller birds) (Jenkins 1995; Franke et al. 2020; Bondì et al. 2023; Griffiths and Aaronson 2023). The Peregrine Falcon has a global distribution, while Lanner Falcons can be found across Africa, adjacent Mediterranean countries, and the Middle East, with both considered to be species of Least Concern according to global IUCN assessments (BirdLife International 2021a, 2021b). In sub-Saharan Africa, these falcons often occur sympatrically, although Peregrine Falcons tend to favour higher-altitude nesting ledges compared with the more flexible Lanner Falcons (Jenkins 1995, 2000; McPherson et al. 2021; Bondì et al. 2023).

Nest site selection influences breeding success, with physical characteristics such as protection from weather and predators playing a pivotal role in selection (Jenkins 2000). It is not common for falcons to build nests; instead, falcon species will occupy vacant nests constructed by other species or suitable platforms on sheltered cliffs or ledges in natural settings or on trees and buildings in urban environments (Jenkins 2000; Mak et al. 2021a). Breeding performance and presence between urban and traditional environments remain variable across species, even with persistence within urban environments (Kettel et al. 2019; Seress et al. 2020). Peregrine Falcons are limited by their preference for landscapes with elevated cliff nest sites with sheltered ledges, while Lanner Falcons are more flexible with nesting habitat preference (Jenkins and Benn 1998; Jenkins 2000; Bondì et al. 2023). Lanner Falcons have less specific nesting requirements and are more generalised feeders and thus can occupy a wider variety of habitats than the Peregrine Falcon (Jenkins 1995; Seress et al. 2020; Bondì et al. 2023). In natural environments, falcons will typically nest and have their breeding ranges centred around cliffs, as this forms optimal protection from terrestrial predators and climatic conditions and provides elevated perches to hunt (Jenkins 2000). In urban environments, ledges of tall buildings form an equivalent of nest sites to steep cliffs in natural environments (Tryjanowski et al. 2021; Mak et al. 2021a). However, land use changes can reduce suitable breeding habitats for both species and alter biotic interactions, potentially affecting their coexistence (De Rosa et al. 2019). In areas of overlap, such as the Mediterranean area, the Peregrine Falcon has been observed to displace the Lanner Falcon at its breeding sites (De Rosa et al. 2019).

Citizen science has become an invaluable tool for ecological data collection, offering valuable insights for conservation and research across Africa (Brown et al. 2019; Lee and Hammer 2022; Lee et al. 2023). The Southern African Bird Atlas Project (SABAP) has

proven especially useful for monitoring bird population trends in South Africa, both for resident and migrant species (Lee and Hammer 2022), and for specific species-focused studies (Brown et al. 2019; Lerm and Underhill 2019). Research questions surrounding raptors within Africa have mainly used a combination of telemetry and fieldwork for data collection (Bijlsma et al. 2023; Shaw et al. 2024), but increasingly, citizen science contributes to conservation at a landscape or land use level (Lepczyk 2005; McPherson et al. 2021).

In this study, we used citizen science as a tool to determine the distribution and trends of the Peregrine Falcon and the Lanner Falcon across South Africa, including Lesotho and Eswatini. By analysing data from SABAP, we compared the presence and distribution of these falcons between two time periods: SABAP1 (1987–1992) and SABAP2 (2007–2024). Our objective was to assess these species' historical and present relative abundance in the region. Given urban expansion and population growth, we hypothesised that there would be a change in these species' populations and distribution ranges. We predicted an overall increase in the abundance of both falcons, especially in urban mosaic landscapes. We also predicted that the Peregrine Falcon would displace and outcompete the Lanner Falcon in areas of overlap.

3.3 Methods

3.3.1 Study area

For our assessments, we considered the countries of South Africa, Lesotho, and Eswatini, as these are the southern African countries with the greatest number of contributions to the SABAP2 project, and allowed comparison between historical (SABAP1, 1987 - 1992) to present distributions (SABAP2, 2007 - ongoing as of 2024).

3.3.2 Data collection

SABAP provides an overview of bird distribution and presence ranges across southern Africa (Brooks et al. 2022; Daniel and Underhill 2023). The data in SABAP1 and SABAP2 consist of checklists by citizen science birdwatchers in defined geographic grids. The number of times a species has been reported across a set of lists is referred to as reporting rate (Brooks et al. 2022). The data for SABAP1 were collected between 1987 and 1992 within a quarter-degree grid cell (henceforth referred to as QDGC) resolution, which is measured by a grid of 15 minutes of latitude and by 15 minutes of longitude (Harrison et al. 1997). The SABAP2 data were collected in pentad data format (resolution grid of 5' by 5'), with nine pentads in a QDGC. These were amalgamated to allow comparisons between SABAP1 and SABAP2 (Lee et al. 2017; Brown et al. 2019; Daniel and Underhill 2023). Data for the comparison of SABAP1 and SABAP2, and within SABAP2 reporting rates, were downloaded from the SABAP project website on 31 March 2024 for the Peregrine Falcon (species number = 113) and the Lanner Falcon (species number = 114), which was accessed through http://sabap2.birdmap.africa/species/113 and http://sabap2.birdmap.africa/species/114, respectively.

3.3.3 Data analyses

The SABAP data provides an indication of range and abundance across southern Africa (Brooks et al. 2022; Daniel and Underhill 2023). Comparisons of temporal periods can be used to show abundance and distributional changes using various statistical techniques (Brooks and Underhill 2017). We used the SABAP1 and SABAP2 data to compare the reporting rates and infer population and distribution changes of the falcons.

To account for any sampling uncertainties, we followed the methods of Brown et al. (2019) to perform bootstrap sampling. We carried out the bootstrap sampling for the range of QDGCs with >4 lists during the SABAP1 and SABAP2 periods. The proportional difference for each sample was calculated as follows:

$$mean(SABAP2\ reporting\ rate) - mean(SABAP1\ reporting\ rate)) / mean(SABAP1\ reporting\ rate).$$

Similarly, the change in occurrence was calculated as follows:

$$(\text{number of SABAP2 QDGCs} - \text{number of SABAP1 QDGCs}) / (\text{number of SABAP1 QDGCs})$$

Our study also examined modified versions of the Z scores (confidence in change scores) and C scores (population change parameters) (Underhill and Bradfield 1998; Underhill and Brooks 2016) using the log-modified version presented by Lee and Hammer (2022). The C score can better account for the non-linear relationship between the reporting rates and the actual abundance (Underhill and Brooks 2016) if the probability of detection is assumed to be constant. The results from this bootstrapping method are presented visually as density plots and maps as implemented by Lee et al. (2024). The 95% confidence intervals are also presented for the range change metrics. These values are considered significant when they do not overlap with 0.

We followed the methods of Lee et al. (2023), using full protocol cards for SABAP2 to analyse the falcons' relative abundance and range change over the past 18 years (2007-2024). We compared the SABAP2 period from 2007 to 2015 (early period) and 2016 to 2024 (late period). We analysed the SABAP data by computing maps of reporting rate change and changes in matrices using R (Version: 4.4.0) (R Core Team 2024).

3.3.4 Competition and abundance

We compared ranges and measures of abundance (reporting rate) for the two species at the QDGC level and examined the percentage difference in reporting rate for areas of co-occurrence and absence. We correlated percentage change for that set of QDGCs where the species co-occurs using a standard linear model with the percentage change in peregrine reporting rates as a function of lanner percentage change in reporting rates, with QDGCs as the sampling units. Using the SABAP2 data, we examined the reporting rates and reporting rate percentage difference of each species as a function of the presence of the other species, using standard linear models. In addition, we used South Africa's land use and land cover data set from 2022 to classify each pentad as urban or rural using scaled percentage cover and ran standard linear models to determine the reporting rate and change in reporting rate as a function of urban cover (DFFE 2020). In this case, we used all the available data for each species (rather than just co-occurrence).

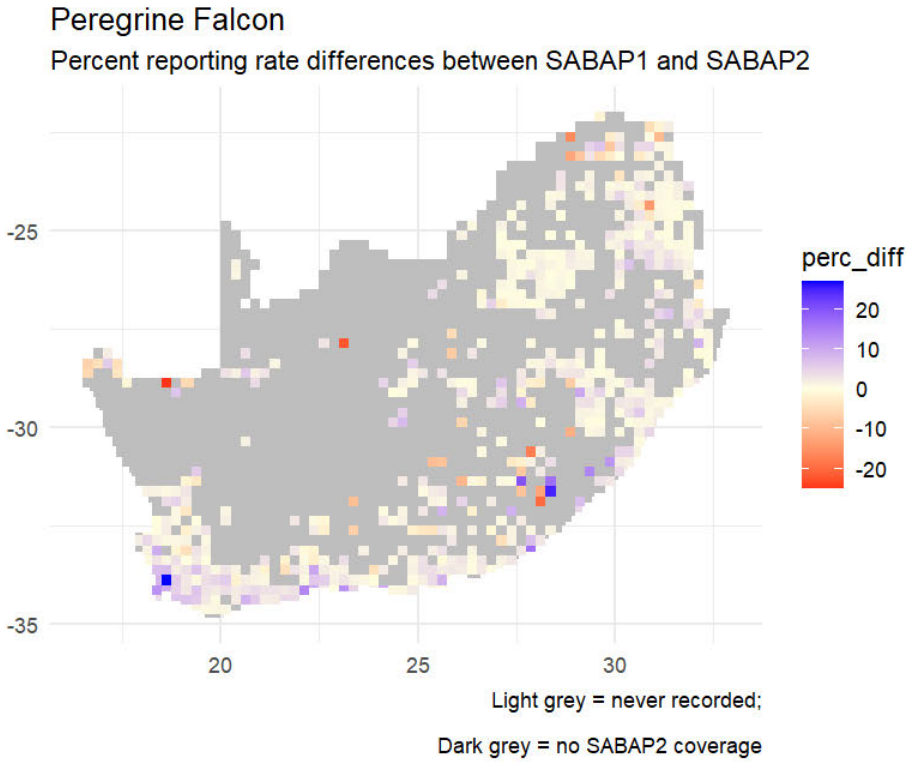
3.4 Results

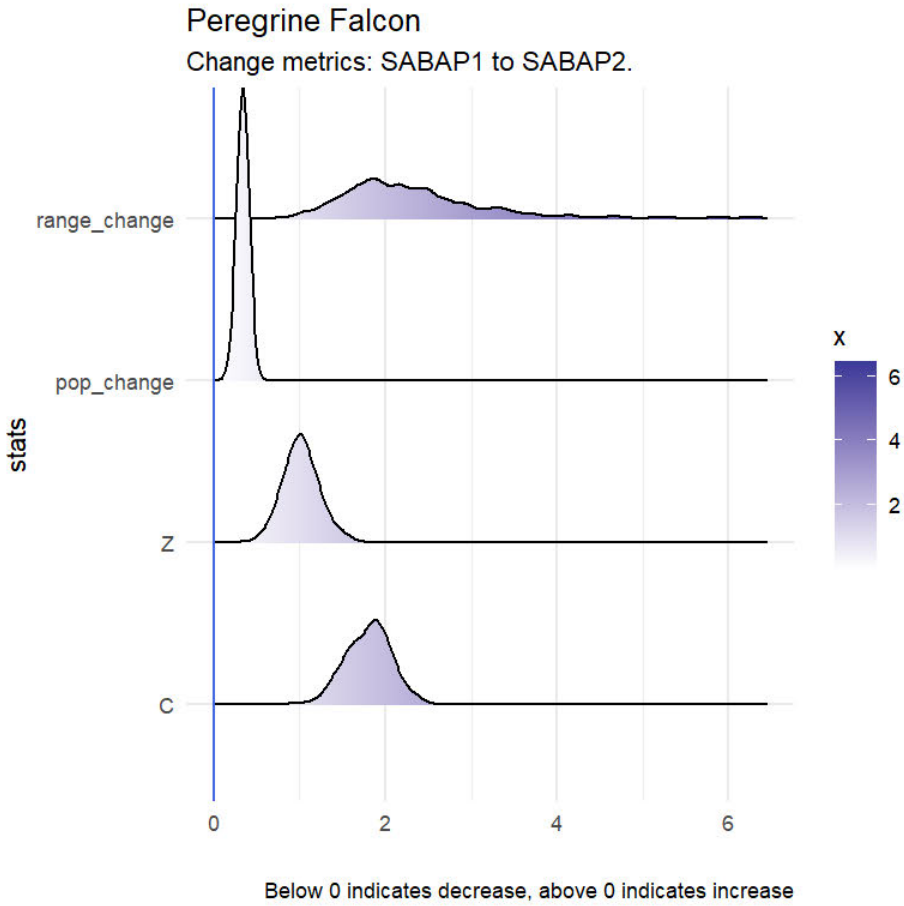
3.4.1 Peregrine Falcon

During SABAP1 (1987-1992), Peregrine Falcons were recorded in 174 QDGCs, while during SABAP2 (2007-2024), they were recorded in 548 QDGCs. In addition, the reporting rates were higher for the SABAP2 period (reporting rate change 95% CI:0.34 – 0.345; Z score: 1.012 – 1.038; C score: 1.824 – 1.857). Across the Peregrine Falcons' historical range, the mean reporting rate was higher in SABAP2 (2.5 $\pm$ 3.00%) than the reporting rate in SABAP1 (0.98 $\pm$ 2.63%). During SABAP1, the median reporting rate was 0. Within SABAP2, Peregrine Falcons were recorded in 666 pentads for the early period (from 2007-2015) and 882 pentads for the late period (from 2015-2024). Further comparison within this falcons

range shows that the reporting rate within SABAP2 was 2.8% for the early period and 1.2% for the late period. These statistics suggest that overall, there was a higher probability of the Peregrine Falcon being recorded over time, according to these citizen science data.

a)


Peregrine Falcon
Percent reporting rate differences between SABAP1 and SABAP2
-25
-30
-35
20
25
30
perc_diff
20
10
0
-10
-20
Light grey = never recorded;
Dark grey = no SABAP2 coverage


Peregrine Falcon
Change metrics: SABAP1 to SABAP2.
range_change
pop_change
Z
C
stats
0
2
4
6
x
6
4
2
Below 0 indicates decrease, above 0 indicates increase

b)

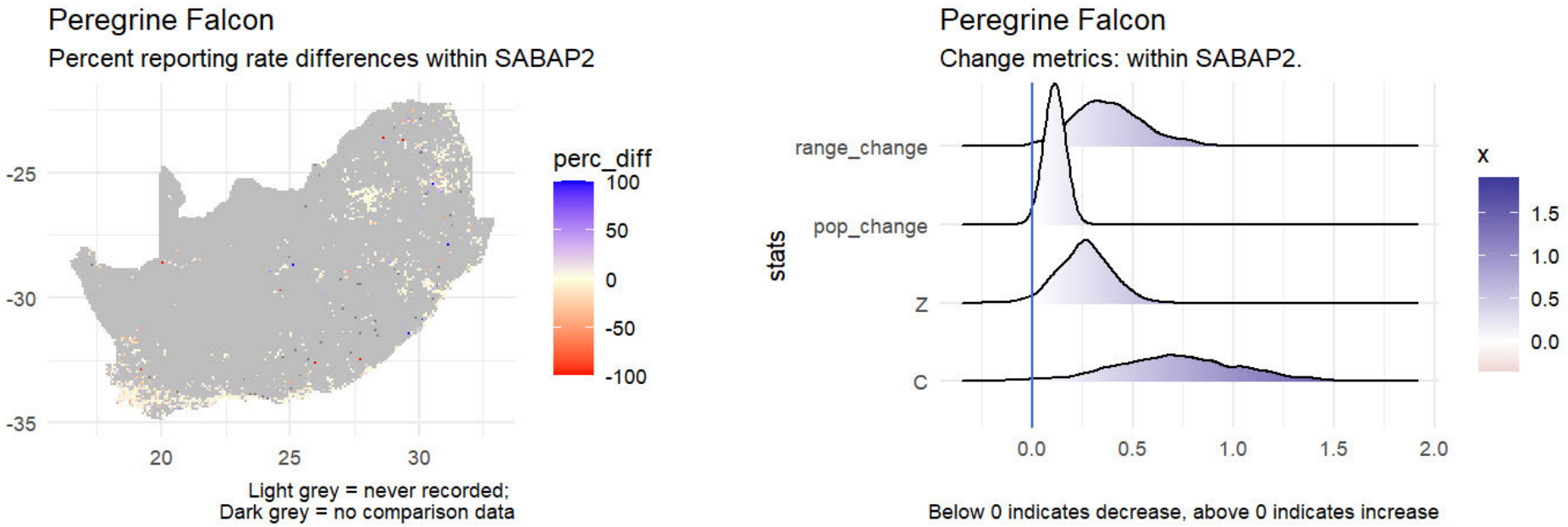
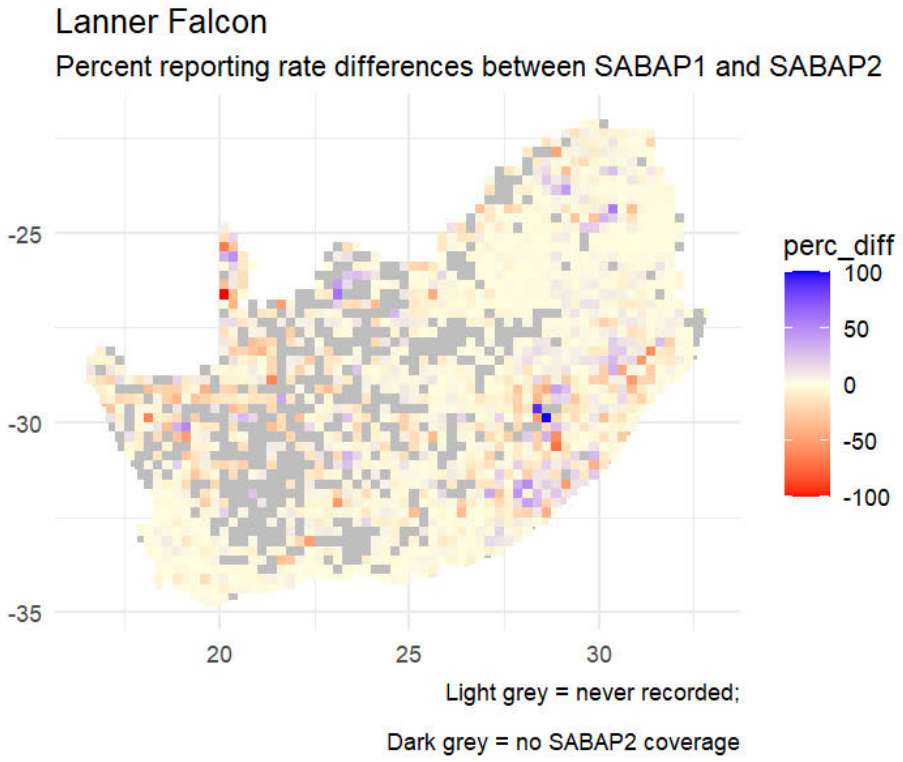


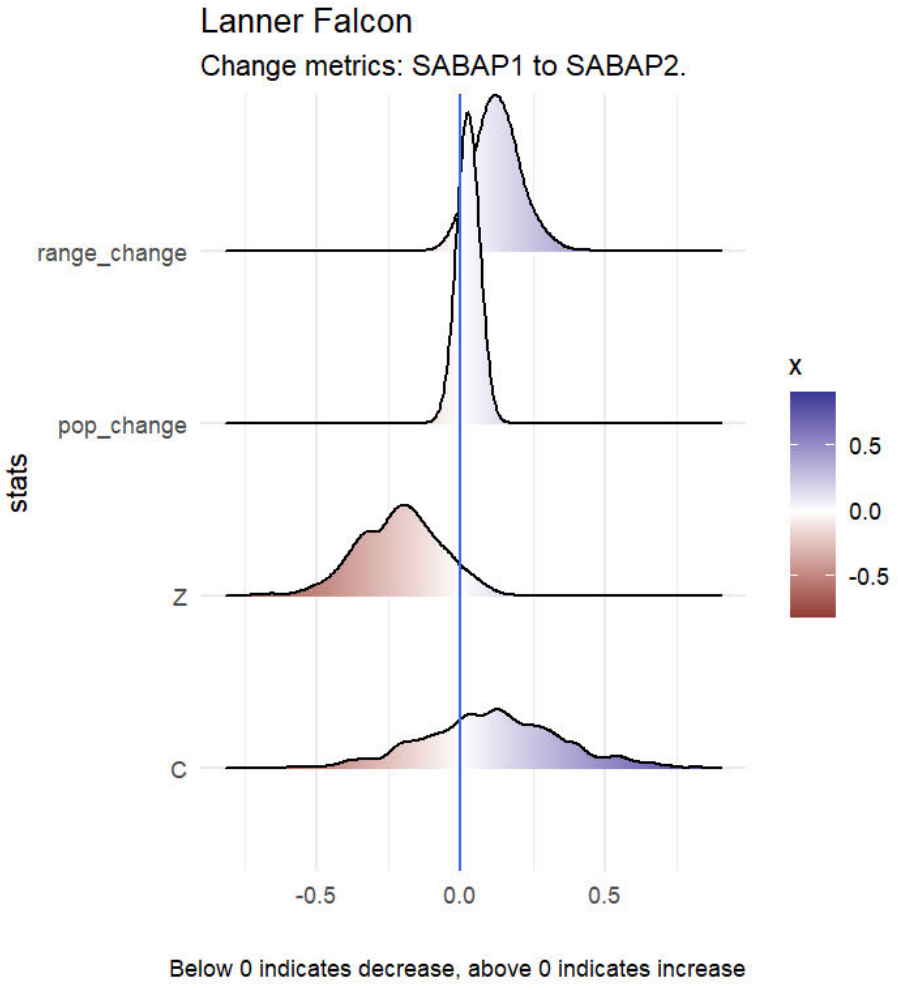
Figure 3.1: a) Quarter Degree Grid Cell level reporting rates differences (percentages, 'perc_diff') between SABAP1 (1987-1992) and SABAP2 (2007-2024) and b) representation of pentad level reporting rates differences (percentages, perc_diff) within SABAP2, comparing the early period (2007-2014) and late period (2015-2024) for Peregrine Falcons in southern Africa, Lesotho, and Eswatini. (Note: Positive values are represented by blue shades; light and dark blue cells indicate an increase in percentage reporting rate difference, while negative values are represented by red shades; light and dark red cells indicate a decrease in percentage reporting rate difference). Yellowish cells represent stability in the reporting rates between the SABAP1 and SABAP2 periods. Dark and light grey cells represent cells with no records for the atlas data and no coverage for the SABAP2 period. Changes in metrics plot: the bootstrap samples of range change, Z scores (confidence in change scores), C scores (population change parameters), and reporting rate changes between SABAP1 and SABAP2. Positive values above zero indicate that there is an increase, while negative values that are below zero indicate that there is a decrease).

3.4.2 Lanner Falcon

During SABAP1 (1987-1992), Lanner Falcons were recorded in 1117 QDGCs, while during SABAP2 (2007-2024), they were recorded in 1269 QDGCs. The reporting rates were mixed for the SABAP1/2 period (reporting rate change 95% CI:0.040 – 0.045; Z score: -0.186 – -0.164; C score: 0.244 – 0.274), with an overall higher probability of reporting in SABAP2 but with high confidence of declines (Z scores) in some areas where these have occurred. Across the Lanner Falcons' historical distribution range, the median reporting rate was marginally higher in SABAP1 (3.9%) than the reporting rate in SABAP2 (3.7%). Within SABAP2, we further see Lanner Falcons were recorded in 2501 pentads for the early period (from 2007-2015) and in 2259 pentads for the late period (from 2016-2024). However, further bootstrap confidence intervals for Z and C scores were all >0. These statistics suggest a marginal increase and a slight decline in detection in the probability of reporting Lanner Falcon in its SABAP2 distribution range overall.

a)


Lanner Falcon
Percent reporting rate differences between SABAP1 and SABAP2
-25
-30
-35
20
25
30
perc_diff
100
50
0
-50
-100
Light grey = never recorded;
Dark grey = no SABAP2 coverage


Lanner Falcon
Change metrics: SABAP1 to SABAP2.
range_change
pop_change
Z
C
stats
-0.5
0.0
0.5
x
0.5
0.0
-0.5
Below 0 indicates decrease, above 0 indicates increase

b.

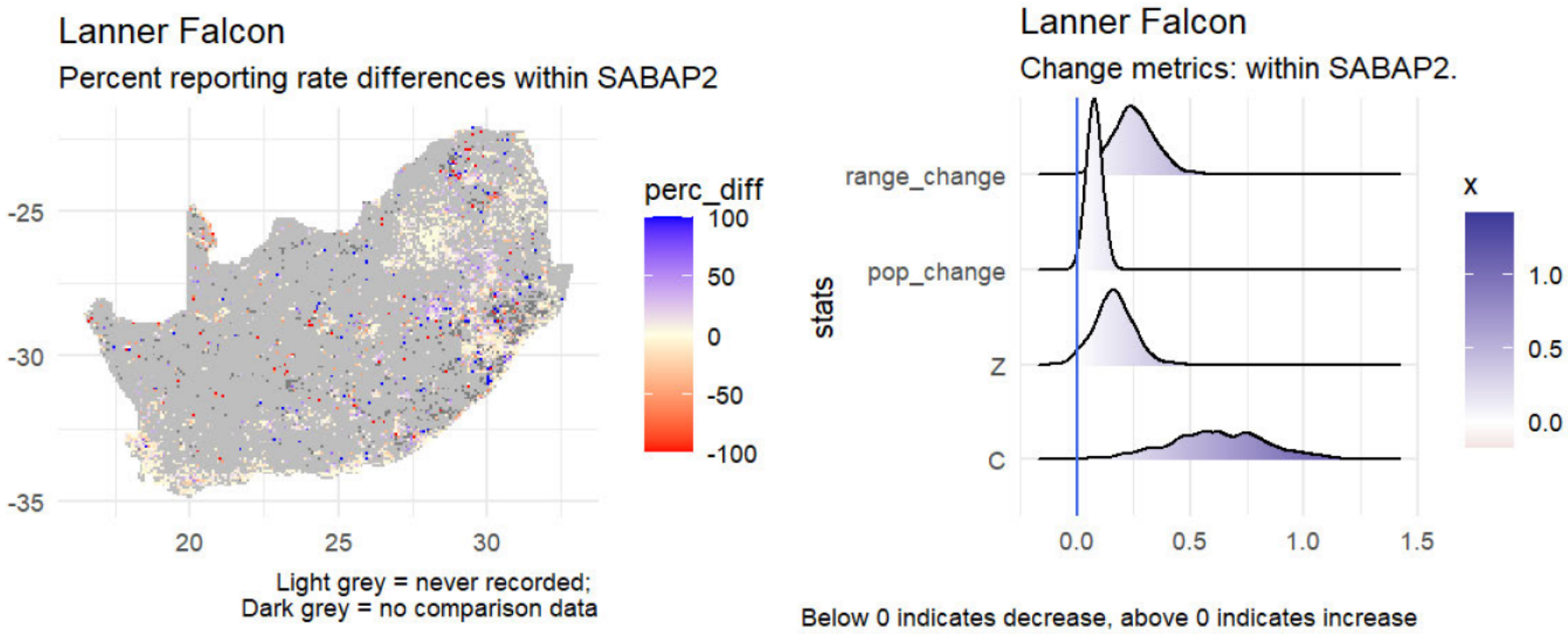


Figure 3.2: a) Quarter Degree Grid Cell level reporting rates differences (percentages, 'perc_diff') between SABAP1 (1987-1992) and SABAP2 (2007-2024) and b) representation of pentad level reporting rates differences (percentages, perc_diff) within SABAP2, comparing the early period (2007-2014) and late period (2015-2024) for Lanner Falcons in southern Africa, Lesotho, and Eswatini. (Note: Positive values are represented by blue shades; light and dark blue cells indicate an increase in percentage reporting rate difference, while negative values are represented by red shades; light and dark red cells indicate a decrease in percentage reporting rate difference. Yellowish cells represent stability in the reporting rates between the SABAP1 and SABAP2 periods. Dark and light grey cells represent cells with no records for the atlas data and no coverage for the SABAP2 period. Changes in metrics plot: the bootstrap samples of range change, Z scores (confidence in change scores), C scores (population change parameters), and reporting rate changes between SABAP1 and SABAP2. Positive values above zero indicate that there is an increase, while negative values that are below zero indicate that there is a decrease).

3.4.3 Reporting rates and QDGCs

Lanner Falcons had a higher number of QDGCs than Peregrine Falcons (Table 3.1). For Lanner Falcons, 22.9% of the QDGCs (n = 334) increased, and 32% decreased (n = 467) in reporting rates. In comparison, 14.6% of the QDGCs showed an increase (n = 85), and 5.7% showed a decrease (n = 33) in reporting rates for Peregrine Falcons (Figures 3.3; Table 3.1). More QDGCs showed a decline (n = 500) than those that showed an increase (n = 419) in reporting rates for both species. Additionally, there were also cells reflecting new records in SABAP2 data, absence in SABAP2 data, no changes in either atlas data, and others which were invalid entries (<4 cards) or never recorded cells (Figures 3.3; Table 3.1). Based on the changes in reporting rates from SABAP1 and SABAP2, there was an overall increase in South Africa, Lesotho, and Eswatini.

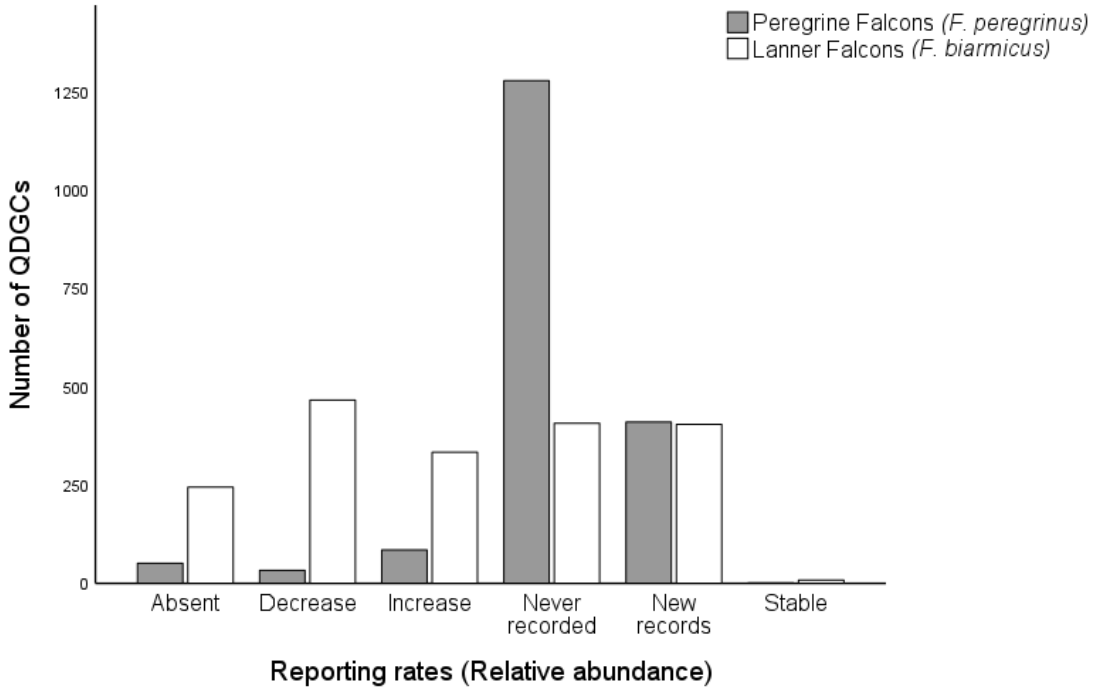


Figure 3.3: Comparison of the reporting rate changes at the Quarter Degree Scale. (representing relative abundance) of Peregrine Falcons (dark grey bars) and Lanner Falcons (light grey bars) between SABAP1(1987-1992) and SABAP2(2007-2024). (Note: "Absent" represents the species that were not recorded in SABAP2 but were recorded in SABAP1, "Decrease" represents a reduction in observations in QDGCs for SABAP2 comparing SABAP1, "Stable" represents no change in observations between the SABAP1 and SABAP2 period, "Never recorded" represents cells that were never recorded for both the SABAP1 and SABAP2 period, "New records" represents the species that were only observed in QDGCs for SABAP2 and not SABAP1, "Increase" represents a rise in observations in QDGCs for SABAP2 in comparison with SABAP1. (Data accessed 04/03/2024).

3.4.4 Competition and abundance

There were only 30 QDGCs over the entire southern African Peregrine Falcons historical distribution range (594 QDGCs) where Lanner Falcons were not recorded. Conversely, there were 966 QDGCs of the historic Lanner Falcon distribution range (1530), which have not recorded Peregrine Falcons, including most of the arid interior of South Africa. Once accounting for outliers, there was no evidence that rates of change in one species were correlated with those in the other species over the mutual distribution range (lm estimate 0.035 ± 0.024, t = 1.44, p = 0.151, df = 531). Across their distribution range, SABAP2 reporting rates for Peregrine Falcons appeared to be independent of Lanner Falcon presence (Table 3.1; lm estimate: No Lanner -0.860 ± 0.571, t = -1.503, p = 0.133). This percentage reporting rate change was significantly more negative in regions without Lanner Falcon (lm estimate: No Lanner: -1.928 ± 0.7352, t = -2.622, p = 0.009). This suggests that where population declines were occurring, these were because of reasons other than Lanner Falcon's presence. Despite an evidently higher reporting rate during SABAP2 compared with SABAP1 (Figure 3.1), especially in the Western Cape around Cape Town, in SABAP2 neither SABAP2 reporting rates nor rates of change were linked to whether a pentad was classed as urban or not, suggesting a low impact of urbanisation on Peregrine Falcon distribution range (reporting rate lm estimate: Urban: 0.287 ± 0.4384, t = 0.654, p = 0.513; reporting rate difference: Urban: 0.4633 ± 0.5475, t = 0.846, p = 0.398).

Conversely, there was a marked signature of Peregrine Falcon presence on Lanner Falcon abundance and declines. For both SABAP1 and SABAP2, reporting rates of Lanner Falcon were lower where Peregrine Falcons co-occurred (Table 3.1; SABAP2 lm estimate: Peregrine Falcon present: -3.648 ± 0.547, t = -6.67, p < 0.001). For reporting rate differences between SABAP1

and SABAP2, which were negative overall for Lanner Falcon, these changes were greater where Peregrine Falcons occurred (Table 3.2). For differences in the SABAP2 period, where Lanner Falcons showed overall increases in reporting rate, the positive changes were lower where Peregrine Falcons occurred (Table 3.2; lm percent difference estimate with Peregrine Falcon present: -1.212 ± 0.582, t = -2.085, p = 0.037). Lanner reporting rates were significantly lower in pentads classed as 'urban' (Urban: -1.444 ± 0.5686, t = -2.539, p = 0.011), although declines were only marginally explained by this variable (Urban: -1.132 ± 0.599, t = -1.891, p = 0.058). An interaction suggested lower reporting rates in urban pentads with Peregrines but was not significant (Peregrines: Urban -0.627 ± 0.3430, t = -1.827, p = 0.07).

Table 3.1: Regional abundance of Peregrine and Lanner Falcons' distribution ranges (with and without the other species present). The mean (Median) reporting rates (for QDGCs or Pentads with >4 cards for each period) are presented.

	Peregrine Falcon		**Lanner Falcon**
QDGC (SABAP1)			
Lanner	2.55 (1.61)	Peregrine	6.11 (3.16)
No Lanner	1.69 (1.47)	No Peregrine	7.29 (4.17)
Pentad (SABAP2)			
Lanner	4.88 (2.63)	Peregrine	6.74 (3.45)
No Lanner	5.53 (3.12)	No Peregrine	10.3 (6.67)

Table 3.2: Regional change in the Abundance of Peregrine and Lanner Falcons' distribution ranges (with and without the other species present). The mean (SD) Percentage change (for QDGCs or Pentads with >4 cards for each period) are presented.

	Peregrine Falcon		**Lanner Falcon**
QDGC (SABAP1)			
Lanner	1.63 (3.76)	Peregrine	-1.41 (12.5)
No Lanner	-0.302 (5.49)	No Peregrine	-0.536 (5.49)
Pentad (SABAP2)			
Lanner	0.958 (7.7)	Peregrine	1.09 (8.64)
No Lanner	1.57 (10.0)	No Peregrine	2.26 (14.0)

3.5 Discussion

Our study demonstrated notable shifts in the distribution and relative abundance of Peregrine and Lanner Falcons across South Africa, Lesotho, and Eswatini, comparing recent (SABAP2, 2007–2024) with historical (SABAP1, 1987–1992) data. Using SABAP reporting rates as proxies for relative abundance, we observed a moderate overall increase in the reported presence of both species. This increase was evident through higher reporting rates and an expansion in the number of QDGCs where the species were recorded. The changes in reporting patterns suggest that both falcons have adapted to varying degrees of landscape changes over time, though their responses to urbanisation and interspecific competition differ. Although there is of yet no empirical link between actual abundance and SABAP reporting rates for these falcons as there are for other species (Amar et al. 2016; Brown et al. 2019; Lee et al. 2018), the SABAP data do inform us

regarding relative change and interactions between the urban environment and potentially competing species.

The Peregrine Falcon showed a significant increase in reporting rates, particularly in the Western Cape, attributable to adaptability to anthropogenic environments. The species' use of tall buildings and other artificial structures as substitutes for natural cliffs has likely facilitated its expansion in urban mosaics there, aligning with trends observed globally (Kettel et al. 2019). In contrast, Lanner Falcons exhibited a more complex pattern. While they maintained a broad range across rural areas, their reporting rates showed less consistent growth and even declines in some regions, particularly where Peregrine Falcons were more prevalent. This suggests that competitive displacement may be occurring, especially in areas where both species overlap, with Peregrine Falcons potentially outcompeting Lanner Falcons for nesting sites and resources in urbanised built landscapes.

There have been negligible reports of aggressive interactions between sub-Saharan located Peregrine Falcons and Lanner Falcons, with the selection of breeding sites mainly driven by the differences in microhabitat selection (Jenkins and Hockey 2001). In the Mediterranean, however, field observations have reported conflict between the falcons, with the Peregrine Falcon replacing the Lanner Falcon at suitable breeding sites (De Lisio et al. 2009). Despite the smaller distribution range of Peregrine Falcons in South Africa than Lanner Falcons, their more restricted range does not seem to be influenced by the presence of Lanner Falcons, nor negatively by urban presence. This suggests other bioclimatically limiting variables. Conversely, there was a distinct signature of Peregrine Falcon presence on abundance and as an explanatory variable of change for Lanner Falcon distribution/range.

Our findings suggest that anthropogenic factors, particularly urbanisation, have significantly influenced the distribution and abundance of the Lanner Falcon. Lanner Falcons prefer traditional agro-ecosystems, such as grasslands and arable lowlands with cliffs and rugged terrains; however, these habitats are becoming increasingly threatened by the intensification of agriculture and land abandonment (Sarà 2014; Jenkins et al. 2023). Urbanisation, especially urban built landscapes, and the subsequent replacement of natural areas negatively impact Lanner Falcons, which generally show lower tolerance to anthropogenic landscapes (Di Vittorio et al. 2015). Environmental factors, such as rainfall and temperature, play a vital role in Lanner Falcons' breeding success, and their spatial distribution is affected by climatic conditions with specific environmental variables (e.g., vegetation type and altitude) correlating with their presence (Andreotti et al. 2008; Amato et al. 2021).

The Peregrine Falcon's reporting rates were not negatively affected by urban areas, which aligns with global trends where this species persists well in urban built environments (Kettel et al. 2019; Mak et al. 2021a; McPherson et al. 2021). Lee et al. (2021) found that African pentads in urban or semi-urban areas had a lower species richness than in rural areas. However, when urbanisation is maintained at intermediate levels through methods that consider ecological balance to minimise the negative impacts on urban biodiversity, such as promoting green infrastructure in cityscapes, then species richness becomes more similar to rural pentads (Tarsitano 2006; Lee et al. 2021). The availability of tall buildings that mimic natural cliff faces, coupled with a steady supply of prey species, has likely contributed to the observed population growth in these areas. This supports previous studies (e.g., Mak et al. 2021b; Searle et al. 2023) that have highlighted the Peregrine Falcon's ability to exploit urban habitats.

Conversely, the Lanner Falcon showed a more complex pattern, with mixed trends in different regions. While some areas saw increased reporting rates, particularly in less urbanised regions, abundance appeared lower in regions where Peregrine Falcons were more prevalent. This suggests potential competitive exclusion, where the more adaptable Peregrine Falcon may be outcompeting the Lanner Falcon, especially in urban areas. The two falcons are morphologically similar and overlap in diets, which would predict competitive exclusion (Sarà et al. 2016). Differences in environmental attributes, such as using diverse cliff substrates for breeding during different seasonal times, would instead predict coexistence (Sarà et al. 2016). However, our findings are consistent with studies on interspecific competition among raptors (Sarà et al. 2016; De Rosa et al. 2019), where sympatric species with overlapping niches often experience competitive pressures that can lead to shifts in population dynamics.

The SABAP data also indicated that the Peregrine Falcon's urban success has not come at the expense of rural populations, as there was no significant decrease in reporting rates in non-urban areas. This suggests that the Peregrine Falcon is maintaining healthy populations across a range of habitats, further underscoring its ecological versatility (Mak et al. 2021b). In contrast, the Lanner Falcon's reliance on more specific habitat conditions, such as open landscapes for hunting, may make it more vulnerable to habitat fragmentation and urban encroachment (Sarà 2014; Amato et al. 2021). Lanner Falcons are also more sensitive to climatic changes than the Peregrine Falcon, with weather conditions linked to shifts in breeding phenology (Sarà et al. 2022). Sub-Saharan species of the Peregrine and Lanner Falcons have shown negligible rates of aggressive interactions compared with the Mediterranean, where active fighting occurs, with the Peregrine Falcon replacing the Lanner Falcon at suitable breeding sites (De Rosa et al. 2019).

Despite these insights, the use of citizen science data from SABAP presents certain limitations. The variability in observer effort and the potential biases in data collection must be considered when interpreting these results. However, the large dataset and the extensive temporal coverage provided by these platforms offer a valuable resource for long-term monitoring and analysis. Future research should aim to complement these findings with more targeted field studies and telemetry data to validate and refine our understanding of these trends.

Overall, this study highlights the importance of considering both natural/non-anthropogenic and anthropogenic factors in raptor conservation strategies. The differing responses of Peregrine and Lanner Falcons to urban built environments emphasise the need for species-specific management plans that account for their unique ecological requirements. As urban built areas expand, proactive measures may be necessary to ensure that both species can coexist and thrive in rapidly changing anthropogenic landscapes. Particularly in the Mediterranean, Peregrine Falcons have been shown to displace Lanner Falcons at nest sites, in both natural and urban settings (Amato et al. 2014; De Rosa et al. 2019). The results from this study show that Lanner Falcons reporting rates were lower in areas where Peregrine Falcons were present and lower in urban areas. Both species occur in urban areas and are becoming more urbanised (to varying degrees). Using artificial nestboxes in urban areas is one solution to mitigate possible competition between these falcons by providing options for suitable nest sites, reducing the need for competition (Catry et al. 2013; Sumasgutner et al. 2020). Artificial nestboxes are recommended here to increase the breeding success of these falcons in urban areas but also to reduce potential competition by providing more options for suitable nest sites, thus reducing the need for competition for suitable nest sites.

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CHAPTER 4

Using social media to document the persistence of the Peregrine Falcon and the Lanner Falcon across South Africa

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Running header: Using social media to determine the presence of Peregrine and Lanner falcons

4.1 Abstract

Social media and networking platforms are growing in their usefulness in research through citizen science contributions. We used diverse online data sources and methods to generate insight into the distribution, ecological interactions, and any additional observed information on the Peregrine (*Falco peregrinus*) and Lanner Falcons (*F. biarmicus*) in South Africa. We use social media, specifically Facebook®, eBird®, and iNaturalist®, to collect posts/observations, images, and any additional information on the two falcon species in South Africa. We collected and analysed 5070 images from 2702 observations/posts in South Africa that were sourced from social media up to the 31st of August 2024. Peregrine Falcons were observed 1154 times, resulting in 2404 images, while Lanner Falcons were observed 1548 times, resulting in 2666 images. Post-2017, there was a significant rise in posts/observations for both falcon species. Both falcons were observed/posted in all nine provinces of South Africa. Lanner Falcons were observed/posted more in most provinces, except Gauteng and the Western Cape, where Peregrine Falcons dominated the observations/posts. The Western Cape Province dominated image observations and posts/observations for the Peregrine Falcon, while the Northern Cape Province was notable for the Lanner Falcon. The differences in images and post/observation contributions between Peregrine Falcons and Lanner Falcons highlight varying levels of visibility and engagement for reporting sightings among the different species, as well as behaviours of the two species. Future research can focus on optimising data collection strategies across multiple platforms to ensure citizen scientists can effectively contribute to our understanding of these species of falcons' dynamics in South Africa.

Keywords: Citizen science; social media; falcons; South Africa

4.2 Introduction

Human-derived pressures on the environment are causing species to decline globally because of agricultural expansion, pollution and disease, climate change, invasive species, habitat loss and degradation, overexploitation and unstable use of natural resources, and anthropogenic activities (Shinwari et al. 2012; Porter et al. 2013; Chowdhury et al. 2022). Climate change has caused global redistribution of species, resulting in new methods and strategies needing to be implemented to monitor and track species distribution and movement, both actively and passively (Pecl et al. 2017; Bonebrake et al. 2018; Taheri et al. 2021; O'Neill et al. 2023). Additionally, urbanisation reduces biodiversity, alters species interactions and ecosystem services, and the response of wildlife differ (based on factors: life history, behaviour, physiological attributes), displaying tolerance or avoidance, or in some cases, a preference for urban environments, thus urban wildlife research is of growing importance (Rodewald and Gehrt 2014; Collins et al. 2021; Awoyemi and Ibánez-Álamo 2023). Many species of interest remain poorly studied or understood because of difficulties such as inaccessible areas, insufficient sample sizes, lack of data, lack of enough observations, lack of observers, funding constraints, lack of interest, and limited opportunities to study a particular species (Dar et al. 2012; Rault et al. 2013; Mammola et al. 2023). Many developing countries do not have proper systems for biodiversity monitoring, while developed countries widely practice systematically recording biodiversity data (Mulatu et al. 2017; Chowdhury et al. 2022). This creates a global biodiversity knowledge gap that citizen science can aid in mitigating. Public awareness and participation play a vital role in wildlife conservation. Social media can enhance public awareness and involvement through widely accessible and user-friendly platforms

like Facebook®, Twitter®, iNaturalist®, Instagram®, blogs, YouTube®, and wikis (Angarita-Sierra et al. 2022; Chowdhury et al. 2023a).

Social media is rapidly advancing, and access to mobile phones with cameras is becoming more and more common (Maritz and Maritz 2020). Social media enables people to interact with people from around the world via the internet, making use of "posts" and "updates", which can be images, videos, tests, audio, or a combination of these (Deng et al. 2012; Rault et al. 2013; Greenhow and Chapman 2020). As a result, with the increasing access to and use of social media platforms, there is a subsequent increase in people posting biodiversity photographs/videos both directly and indirectly (with biodiversity appearing in the background) on platforms such as Facebook® (Chowdhury et al. 2023a). Thus, social media platforms can be used as effective tools for conservation, particularly in their ability to be widespread, connecting individuals of multiple languages and backgrounds from rural and urban areas (Angarita-Sierra et al. 2022; O'Neill et al. 2023). Social networking sites work on a global scale, allowing rapid exchange of wildlife information and even the formation of specific groups dedicated to particular species of interest (Angarita-Sierra et al. 2022; Chowdhury et al. 2022). Social networking sites have seen a rise in posting and public engagement (Middha 2018). The use of social media for research holds great potential in gathering large amounts of biological data (Angarita-Sierra et al. 2022). Media captured and posted by individuals using social media have become increasingly widespread, enabling people to share media with online communities that are also archived (Rault et al. 2013). Citizen science projects can make use of social media to engage with many participants globally, allowing them to contribute to observations and research that can be conducted over a long period

and over a large geographical region (Sullivan et al. 2009; Deng et al. 2012; Chowdhury et al. 2022).

The use of citizen science has become the fastest-growing contributor to occurrence data of birds to increase the knowledge of bird trends and ecology worldwide (Gorleri et al. 2023). Facebook®, in particular, is the largest social media platform in the world, containing thousands of groups globally that are interested in or dedicated to different taxa (Edwards et al. 2021; Chowdhury et al. 2023a). Social media websites, such as Facebook® and Instagram®, act as an informal informational source working in real-time, with the potential to contribute to the detection of early warnings and trends in biodiversity, for example, when looking at shifts in ecosystems, changes in ecological systems, and detection of environmental problems (Edwards et al. 2021). The use of social media platforms to aid in research has become more common; in particular, Facebook® has demonstrated its usefulness through posts and groups gathering data through posts, images, and videos to be compiled and extracted for ecological data (Sullivan et al. 2009; Angarita-Sierra et al. 2022; Chowdhury et al. 2023a). Using social media posts, images, and videos, we can collect metadata about a particular species or taxa, such as time, location, and data (Edwards et al. 2021). Dixon and Smit (2023) found that Facebook® can be a valuable data source; specifically, Facebook® images were used to quantify surface water dependency in southern African arid-zone bird species. Social media, however, is not designed to collect and analyse scientific data. Thus, social media information must be converted to more structured data to achieve the desired scientific objectives (Deng et al. 2012; Gabelaia 2023). The use of social media for biodiversity data collection holds tremendous potential; however, concerns remain regarding the reliability and quality of the information gathered from these platforms (Araújo et al. 2019; Edwards et al. 2021).

Despite the increasing use of citizen science data, the data is frequently viewed as unreliable as the data is primarily collected by non-professional users, and thus, issues such as bias because of misidentification become a factor (Araújo et al. 2019; Gorleri et al. 2023).

The use of social media for data collection is still a relatively recent practice. The implementation of social media for data collection is limited to users' interests and posts on species and taxa. Vertebrates, however, have generated the most public support and engagement on social media platforms, specifically large mammals and birds (Angarita-Sierra et al. 2022). The study by Maritz and Maritz (2020) used a dedicated Facebook® group for reptile enthusiasts and researchers to post observations that can be stored and later recorded. Using methods such as this, social media and communicative platforms can be used as internet-based data (Middha 2018; Fox et al. 2022; Otero et al. 2024).

The Peregrine Falcon (*Falco peregrinus*) and Lanner Falcon (*F. biarmicus*) are medium to large cliff-nesting falcons that occur sympatrically throughout sub-Saharan Africa (Jenkins 2000a; Jenkins 2000b; Sumasgutner et al. 2020). The Lanner Falcon is more widely distributed and common in South Africa than the Peregrine Falcon, which has a higher degree of habitat specificity (Jenkins 1998; Jenkins 2000a). Peregrine Falcons are rarer in South Africa than Lanner Falcons; however, they outnumber the Lanner Falcons in the temperate southwest (Jenkins 1998; Jenkins 2000a). These falcons can be found in natural environments but can also be found exploiting urban areas (Sumasgutner et al. 2020; Jenkins et al. 2023). Generally, the Peregrine Falcon can thrive in urban areas, and has colonised urban areas globally, whereas the Lanner Falcon can occupy urban areas but prefers more natural cliff-nesting sites with intact woodlands and forests (De Rosa et al. 2019; Sumasgutner et al. 2020; Jenkins et al. 2023). Consistent falcon monitoring can pose several

challenges because of their wide distribution, movement patterns, high flight speeds, poor visibility, and their diverse and often remote habitat selection (Snowdon et al. 2018; Franke et al. 2020). Many monitoring efforts are well established; however, challenges still exist with the commonly used methodology that may hinder more comprehensive data collection. For example, wireless tracking devices are commonly used but are limited by battery life and thus are not always sufficient for long-term monitoring (Snowdon et al. 2018). There are workarounds to issues such as this; however, diversifying methodologies may be an effective solution to enhance data collection and monitoring programs.

In this study, we used social media, specifically Facebook®, eBird®, and iNaturalist®, to collect posts/observations, images, and any additional information on Peregrine Falcons and Lanner Falcons. We used diverse online data sources and methods to generate insight into the distribution, ecological interactions, and any additional observed information that can be gathered on the Peregrine and Lanner Falcon from social media posts/observations. We predicted the Lanner Falcons would be more widely posted across South Africa with more posts, given that they are an Afro-tropical species.

4.3 Methods

4.3.1 Sampling techniques

We collected social media data through manual searches on Facebook®, eBird®, and iNaturalist® posted before 31st of August 2024. Searches were performed on these social media networks, making records of posts in South Africa containing Peregrine Falcons and Lanner Falcons. Posts published were not limited by a start date; all identified posted information regarding either falcon

was recorded. All published posts were available for public access and were able to accumulate Likes, shares, and comments from fellow users. Searches on Facebook® group posts were conducted during the sampling period, querying the platforms' browsers using keywords (i.e., Peregrine Falcons, Peregrine, Falcons, Lanner Falcons, Lanner) (Supplementary Information Table S4.1). Due to the possibility of reposting sightings on Facebook®, new and old Facebook® groups were looked at, and repeated or reposted images and posts/observations were excluded. Facebook® users can generate qualitative data for analysis through posts, videos, images, comments, and reactions. For this study, we focused on user-generated posts that include mention/appearance of the Peregrine Falcon and/or Lanner Falcon. Posts and images of our study species were obtained using Facebook®, eBird®, and iNaturalist® searches. Relevant observations from iNaturalist® citizen science platform (https://www.iNaturalist.org) and eBird® (https://www.ebird.org) were categorised. Each post and image were classified based on the information observed in the posts and pictures (date, location, number of images, the observed activity in the image, intraspecific and interspecific interactions). The year that observations were made was considered instead of the year of posting; thus, observations were not limited. The observed images were classified into five categories (flight, prey capture and handling, resting behaviour, interspecific interactions, and intraspecific interactions) based on the activity observed by the falcon. Interspecific interactions were divided into three categories: aggressive, neutral, and defensive. Aggressive interactions were when the falcons were aggressive towards other species, defensive interactions were when other species were aggressive towards the falcons, and neutral interactions were when no aggression or defensive displays were evident. Intraspecific interactions were similarly categorised into three categories (positive, neutral, and negative). Positive

interactions were beneficial interactions between the same species of falcons, such as feeding young, while negative interactions were non-beneficial interactions, such as fellow falcons stealing prey from one another, while neutral interactions were neither beneficial nor non-beneficial interactions.

4.3.2 Data analyses

We summarised the data obtained from Facebook®, eBird®, and iNaturalist® using descriptive statistics on Microsoft Excel® (Version 2411). The frequency of observations/posts on social media data was analysed to establish trends and the range of data. Additionally, a Chi^2 test was conducted in Microsoft Excel® to determine if there was a significant difference in the quantity of posts between the two falcons.

We performed Kruskal-Wallis tests to determine if there were significant differences in the frequency of individual observations for the two species of falcon in SPSS® (version 29). Years before 2010 were combined because some years had fewer than five observations per year, which would violate the assumption of sufficient expected frequencies for the test.

To determine if there was a difference in the frequency of image activity from the five image activities for each falcon independently, a one-way analysis of variance (ANOVA) was performed using SPSS® (version 29). The independent variable was the image activities, and the dependent variable was the frequency of the observed image activity. Data normality was assessed using a One-Sample Kolmogorov-Smirnov Test, and the assumption was not satisfied ($p < 0.001$). The frequency of image activity observed was transformed using a $\log_{10}$ transformation, and the One-Sample Kolmogorov-Smirnov Test was run again. The transformed data resulted in the

assumption being satisfied ($p = 0.20$). To determine if there was equality of variance, we ran a Levene's test, and the assumption was satisfied ($p = 1.00$). The data were assumed to be independent.

To determine if there was a difference in the frequency of image activity from the nine provinces in South Africa for each falcon independently, a one-way ANOVA was performed using SPSS® (version 29). The independent variable was the province, and the dependent variable was the frequency of image activities observed. The assumption that the data is normally distributed was assessed using a One-Sample Kolmogorov-Smirnov Test, and the assumption was not satisfied for the Peregrine Falcon ($p < 0.001$). The frequency of image activity observed was transformed using a $\log_{10}$ transformation, and the One-Sample Kolmogorov-Smirnov Test was run again. The transformed data resulted in the assumption being satisfied ($p = 0.052$). The assumption that the data were normally distributed was satisfied for the Lanner Falcon ($p = 0.061$). A Levene's test was run to determine if there was equality of variance, and the assumption was satisfied for both falcons ($p = 1.00$).

To determine if there was a difference in the images observed for both falcons that were classified as prey capture and handling, a Chi^2 test was conducted in Microsoft Excel®. Kruskal-Wallis tests were performed to determine if there was a significant difference in the frequency of image observations classified as prey capture and handling individually for the two falcon species in SPSS® (version 29).

To determine if there was a difference in the images observed for both falcons that were classified as interspecific interactions, a Chi^2 test was conducted on Microsoft Excel®. Kruskal-Wallis tests were performed to determine if there was a significant difference in the frequency of

images observations classified as interspecific interactions individually for the two species of falcon in SPSS® (version 29).

To determine if there was a difference in the images observed for both falcons that were classified as intraspecific interactions, a Chi^2 test was conducted in Microsoft Excel®. Kruskal-Wallis tests were performed to determine if there was a significant difference in the frequency of image observations classified as intraspecific interactions individually for the two species of falcon in SPSS® (version 29).

4.4 Results

4.4.1 Social media overview

We obtained 2702 observations for both falcons, and 5070 images were extracted from those observations. There were 1154 observations on the Peregrine Falcon with 2404 images. For the Peregrine Falcon, iNaturalist® contributed 37.3% (n = 430), Facebook® 44.0% (n = 508), and eBird® 18.7% (n = 216) of total observations (n = 1154) (Table 4.1). iNaturalist® contributed 41.0% (n = 986), Facebook® 45.9% (n = 1103), and eBird® 13.1% (n = 315) of total images (n = 2404) for the Peregrine Falcon (Table 4.1). Facebook® had the most observations for both species.

There were 1548 observations and 2666 images for the Lanner Falcon. iNaturalist® contributed 36.1% (n = 558), Facebook® 39.0% (n = 603), and eBird® 25.0% (n = 387) of total observations (n = 1548) for the Lanner Falcon (Table 4.1). Of total images (n = 2666) for the Lanner Falcon, iNaturalist® contributed 40.1% (n = 1070), Facebook® 38.3% (n = 1021), and eBird® 21.6% (n = 575) (Table 4.1).

Table 4.1: Summary of image posts/observations in South Africa of the Peregrine Falcon and Lanner Falcon from social media (Facebook®, iNaturalist®, and eBird®) up until 31st of August 2024.

Province	Falcon		iNaturalist®	Facebook®	eBird®	Totals
Eastern Cape	Peregrine	Observers	12	46	4	62
		Observations	25	110	4	139
		Images	53	210	5	268
	Lanner	Observers	23	52	14	89
		Observations	51	124	24	199
		Images	87	238	32	357
Free state	Peregrine	Observers	2	0	2	4
		Observations	2	0	2	4
		Images	4	0	3	7
	Lanner	Observers	11	2	9	22
		Observations	14	4	10	28
		Images	18	5	25	48
Gauteng	Peregrine	Observers	9	40	9	58
		Observations	14	88	9	111
		Images	31	190	21	242
	Lanner	Observers	9	29	16	54
		Observations	11	46	16	73
		Images	18	56	27	101
KwaZulu-Natal	Peregrine	Observers	25	40	16	81
		Observations	38	54	17	109
		Images	71	134	23	228
	Lanner	Observers	58	56	40	154
		Observations	109	84	64	257
		Images	174	141	81	396
Limpopo	Peregrine	Observers	16	9	16	41
		Observations	19	11	23	53
		Images	37	18	25	80
	Lanner	Observers	23	6	22	51
		Observations	30	12	26	68
		Images	47	19	46	112
Mpumalanga	Peregrine	Observers	9	14	16	39
		Observations	9	20	17	46
		Images	26	25	21	72
	Lanner	Observers	28	14	50	92
		Observations	32	14	61	107

		Images	48	26	83	157
Northern Cape	Peregrine	Observers	11	3	8	22
		Observations	14	3	10	27
		Images	19	3	15	37
	Lanner	Observers	72	80	73	225
		Observations	216	217	127	560
		Images	412	330	184	926
North West	Peregrine	Observers	2	9	0	11
		Observations	2	16	0	18
		Images	3	35	0	38
	Lanner	Observers	9	15	9	33
		Observations	11	43	12	66
		Images	14	73	16	103
Western Cape	Peregrine	Observers	161	99	86	346
		Observations	307	206	134	647
		Images	742	488	202	1432
	Lanner	Observers	51	29	28	108
		Observations	84	59	47	190
		Images	252	133	81	466

4.4.2 Timeline of posts

Lanner Falcons had more observations (n = 1548) across Facebook®, iNaturalist®, and eBird®s combined than Peregrine Falcons (n = 1154) across South Africa (Chi^2 test: $X^2 = 16.089$, df = 2, p = 0.000321)). There was a significant difference in the number of Lanner Falcon observations between the three time periods (before 2010, 2011 - 2016, 2017 – 2024) (Kruskal Wallis: H = 20.786, df = 2, $p < 0.001$). Lanner Falcons' posts before the year 2010 (> ten observations per year) made up 1.9% (n = 30) of the total observations observed (Figure 4.1). Between the years 2010 and 2017, there was an increase in observations per year (10< X <100 observations per year) at 23.0% (n = 356) of the total observations. From 2017 to the present (31st of August 2024), the bulk of observations were made (<100 observations per year) at 75.1% (n = 1162) of the total observations (Figure 4.1).

There was a significant difference in the number of Peregrine Falcon observations between the three time periods (before 2010, 2011 - 2016, 2017 – 2024) (Kruskal Wallis: $H = 15.039$, $df = 2$, $p < 0.001$). Peregrine Falcons observations before 2013 (>15 observations per year) comprised 3.9% ($n = 45$) of the total observations (Figure 4.1). Between the years 2013 and 2018, there was an increase in observations per year ($40 < X < 51$ observations per year) at 20.7% ($n = 239$) of the total observations. From 2018 to the present (31st of August 2024), the bulk of observations were made (<100 observations per year) at 75.4% ($n = 1870$) of the total observations (Figure 4.1).

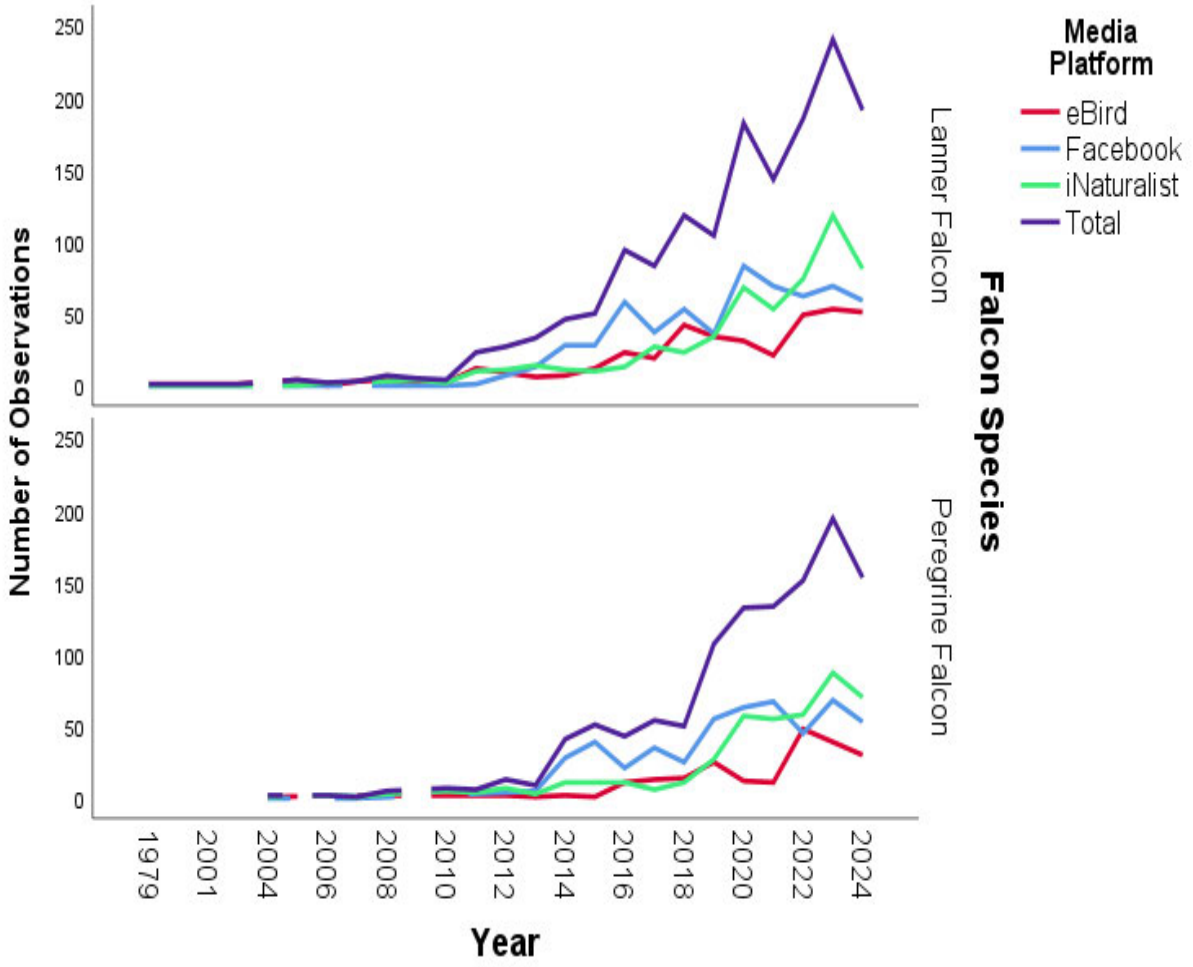

Figure 4.1: Observations per year of the Peregrine Falcon and Lanner Falcon in South Africa from Facebook®, iNaturalist®, and eBird®s up until the 31st of August 2024.

4.4.3 Image observations

A total of 5070 images were posted/observed on Peregrine Falcons and Lanner Falcons in South Africa from Facebook®, iNaturalist®, and eBird®. The Peregrine Falcon had 2404 images from all posts/observations (Table 4.1). The activity categories of the Peregrine Falcons varied significantly among images (ANOVA, F = 3.69, df = 4, p = 0.015). Flight contributed 31.7% (n = 763), interspecific interactions 4.5% (n =109), intraspecific interactions 2.5% (n = 60), prey

capture and handling 17.9% (n = 430), and resting behaviour 43.3% (n = 1042) from all Peregrine Falcons image observations (n = 2404, Figure 4.2). The provincial distribution of the Peregrine Falcon images varied significantly (ANOVA, $F = 2.156$, $df = 8$, $p = 0.066$). The Eastern Cape Province contributed 11.2% (n = 268), the Free State Province 0.3% (n = 7), the Gauteng Province 10.1% (n = 242), KwaZulu-Natal Province 9.5% (n = 228), Limpopo Province 3.3% (n = 80), Mpumalanga 3.0% (n = 72), North West Province 1.6% (n = 38), Northern Cape 1.5% (n = 37), and Western Cape Province the most with 59.6% (n = 1432) from all Peregrine Falcons image observations (n = 2404, Table 4.1).

The Lanner Falcon had a total of 2666 images from all observations. The image activity categories for Lanner Falcons varied significantly among images (ANOVA, $F = 6.653$, $df = 4$, $p < 0.001$). Flight contributed 32.4% (n = 864), interspecific interactions 3.0% (n = 79), intraspecific interactions 2.6% (n = 70), prey capture and handling 15.8% (n = 420), and resting behaviour the most with 46.3% (n = 1233). The provincial distribution of the Lanner Falcon images varied significantly (ANOVA, $F = 2.580$, $df = 8$, $p = 0.024$). The Eastern Cape Province contributed 13.4% (n = 357), Free State Province 1.8% (n = 48), Gauteng Province 3.8% (n = 101), KwaZulu-Natal Province 14.9% (n = 396), Limpopo Province 4.2% (n = 112), Mpumalanga Province 5.9 % (n = 157), North West Province 3.9% (n =103), Northern Cape Province 34.7% (n = 926), and the Western Cape Province 17.5% (n = 466, Table 4.1).

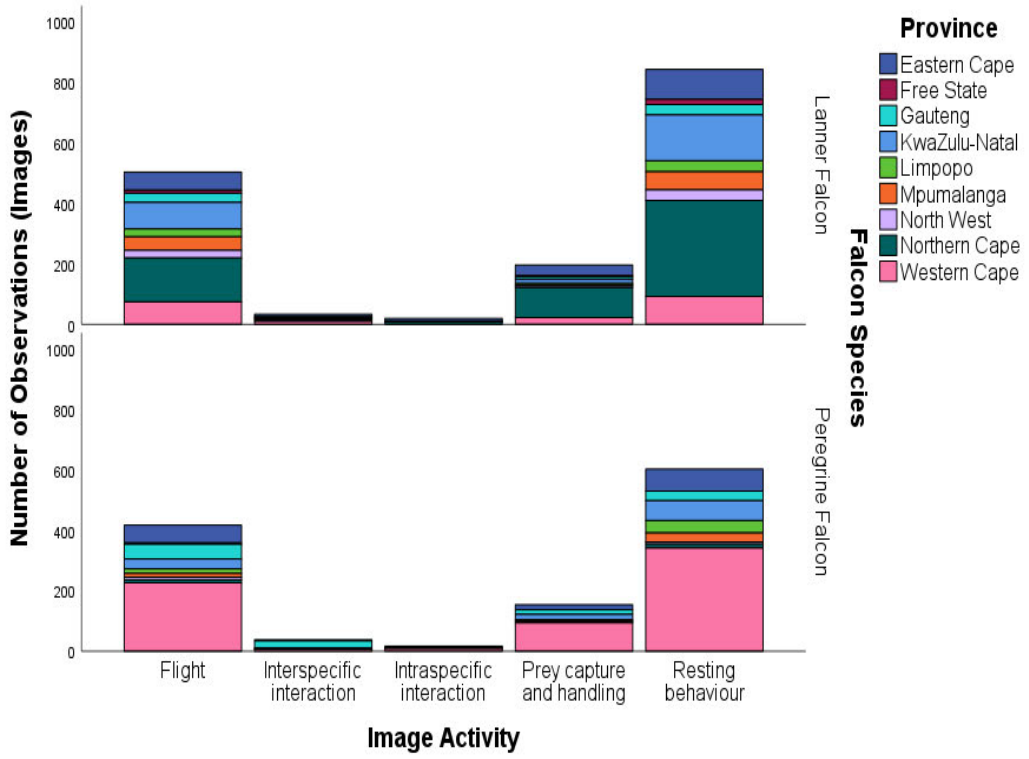

Figure 4.2: Provincial image activity categories based on observations of Peregrine and Lanner Falcons from social media (Facebook®, iNaturalist®, and eBird®s) up until the 31st of August 2024.

4.4.4 Intraspecific interactions

We found 130 images from 37 observations for both falcons classified as intraspecific interactions that did not differ significantly (Chi^2 test: $X^2 = 0.731$, df = 2, p = 0.694). The Peregrine Falcon had 60 images from 18 observations classified as intraspecific interactions (Kruskal Wallis: H =1.686, df = 2, p = 0.43). Negative interactions of Peregrine Falcon contributed 26.7% (n = 16) of images from 33.3% (n = 6) observations. Their negative interactions included aerial combat, which contributed 11.7% (n = 7) of images from 5.6% (n = 1) of observations; bullying, which contributed 8.3% (n = 5) of images from 16.7% (n = 3) of observations; and fighting over prey

which contributed 6.7% (n = 4) of images from 11.1% (n = 2) of observations. Peregrine Falcon neutral interactions contributed 5.0% (n = 3) of images from 11.1% (n = 2) of observations. From their neutral interactions, general interaction contributed 5.0% (n = 3) of images from 11.1% (n = 2) of observations. Peregrine Falcon positive interactions contributed 68.3% (n = 41) of images from 55.6% (n = 10) of observations. Their positive interactions included courtship and mating, which contributed 10.0% (n = 6) of images from 11.1% (n = 2) of observations; feeding young, which contributed 10.0% (n = 6) of images from 16.7% (n = 3) of observations, and playing, which contributed 48.3% (n = 29) of images from 27.8% (n = 5) of observations.

The Lanner Falcon had 70 images from 19 observations classified as intraspecific interactions (Kruskal Wallis: H = 0.120, df = 2, p = 0.942). Negative interactions of Lanner Falcon contributed 12.9% (n = 9) of images from 26.3% (n = 5) of observations. Their negative interactions included aerial combat, which contributed 4.3% (n = 3) of images from 15.8% (n = 3) of observations; bullying, which contributed 1.4% (n = 1) of images from 5.3% (n = 1) of observations, and fighting over prey, which contributed 7.1% (n=5) of images from 5.3% (n = 1) of observations. Lanner Falcon neutral interactions contributed 33.0% (n = 23) of images from 21.1% (n = 4) of observations. Their neutral interactions included communicating, which contributed 7.1% (n = 5) of images from 5.3% (n = 1) observations, and general interaction, which contributed 25.7% (n = 18) of images from 15.8% (n = 3) of observations. Lanner Falcon positive interactions contributed 54.3% (n = 38) of images from 52.6% (n = 10) of observations. Their positive interactions included courtship and mating, which contributed 51.4% (n = 36) of images from 42.1% (n = 8) of observations, hunting lessons contributed 1.4% (n = 1) of images from 5.3%

(n = 1) of observations, and vocalising contributed 1.4% (n = 1) of images from 5.3% (n = 1) of observations.

4.4.5 Interspecific interactions

There were 188 images from 70 observations for both falcons that were classified as interspecific interactions and did not differ significantly (Chi^2 test: $X^2 = 0.358$, df = 2, p = 0.836). The Peregrine Falcon had 109 images from 37 posts/observations classified as interspecific interactions that did not differ significantly (Kruskal Wallis: H = 0.367, df = 2, p = 0.832, Table 4.2). Aggressive interactions from Peregrine Falcons towards other species (aggressive) accounted for 40.4% (n = 44) of images from 48.7% (n = 18) of observations, neutral interactions (neutral) accounted for 40.4% (n = 44) of images from 35.1% (n = 13) of observations, and aggressive interactions from other species towards Peregrine Falcons (defensive) accounted for 19.3% (n = 21) of images from 16.2% (n = 6) of observations (Table 4.2).

The Lanner Falcon had 79 images from 33 posts/observations classified as interspecific interactions that did not differ significantly (Kruskal Wallis: H = 03.543, df = 2, p = 0.170) (Table 4.3). Aggressive interactions from Lanner Falcons towards other species (aggressive) accounted for 51.9% (n = 41) of images from 48.5% (n = 16) of observations. Most of these were with other raptors (Table 4.2). Neutral interactions (neutral) accounted for 31.7% (n = 25) of images from 30.3% (n = 10) of observations, and aggressive interactions from other species towards Lanner Falcons (defensive) accounted for 16.5% (n = 13) of images from 21.2% (n = 7) of observations (Table 4.3).

Table 4.2: Summary of records for interspecific interactions observed from social media up until the 31st of August for the Peregrine Falcon.

	Common name	**Scientific name**	**No. of images**	**No. of observations**
Aggressive	Crowned Eagle	*Stephanoaetus coronatus*	1	1
	Pied Crow	*Corvus albus*	9	3
	Rock Kestrel	*Falco rupicolus*	8	2
	Stork	*Ciconiidae*	1	1
	Verreaux's Eagle	*Aquila verreauxii*	25	11
		Total	44	18
Neutral	Abdim's Stork	*Ciconia abdimii*	1	1
	Crow	*Corvidae*	2	1
	Egyptian Geese	*Alopochen aegyptiaca*	1	1
	Pied Crow	*Corvus albus*	14	2
	Verreaux's Eagle	*Aquila verreauxii*	22	7
	Verreaux's Eagle and Crow	*Aquila Verreauxii* and *Corvidae*	4	1
		Total	44	13
Defensive	Crowned Eagle	*Stephanoaetus coronatus*	2	1
	Pied Crow	*Corvus albus*	11	4
	Sparrowhawk	*Accipitridae*	8	1
		Total	21	6

Table 4.3: Summary of records for interspecific interactions observed from social media up until the 31st of August for the Lanner Falcon.

	Common name	Scientific name	No. of images	No. of observations
Aggressive	Black-winged kite	*Elanus caeruleus*	15	2
	Booted Eagle	*Hieraaetus pennatus*	1	1
	Crowned Eagle	*Stephanoaetus coronatus*	2	1
	Jackal Buzzard	*Buteo rufofuscus*	1	1
	Unidentified	-	3	1
	Verreaux's Eagle	*Aquila verreauxii*	10	4
	Wahlberg's Eagle	*Hieraaetus wahlbergi*	2	2
	Yellow-billed Kite	*Milvus aegyptius*	7	4
		Total	41	16
Neutral	African Harrier-hawk	*Polyboroides typus*	1	1
	Crowned Lapwing	*Vanellus coronatus*	1	1
	Egyptian Geese	*Alopochen aegyptiaca*	1	1
	Kite	*Accipitridae*	1	1
	Pied Crow	*Corvus albus*	6	1
	Raven	*Corvidae*	1	1
	Speckled Pigeon	*Columba guinea*	3	1
	Swifts	*Apodidae*	2	1
	Unidentified	-	9	2
		Total	25	10
Defensive	Booted Eagle	*Hieraaetus pennatus*	4	1
	Crow	*Corvidae*	1	1
	Kite	*Accipitridae*	4	1
	Pied Crow	*Corvus albus*	3	3
	African Sacred Ibis	*Threskiornis aethiopicus*	1	1
		Total	13	7

4.4.6 Prey capture and handling

There were 850 images from 350 observations for both falcons classified as prey capture and handling, which differed significantly (Chi^2 test: $X^2 = 34.51$, df = 6, $p < 0.001$). The Peregrine Falcon had 430 images from 154 observations classified as prey capture and handling, which were not significantly different (Kruskal Wallis: H = 4.498, df = 4, p = 0.343, Table 4.4). From these posts/observations avian prey accounted for 68.4% (n = 294) of images from 67.5% (n = 104) of observations, Chiroptera prey accounted for 0.9% (n = 4) of images from 1.3% (n = 2) of observations, insect prey accounted for 0.2% (n = 1) of images from 0.7% (n = 1) of observations, reptile prey accounted for 1.6% (n = 7) of images from 0.7% (n = 1) of observations, and unidentified prey accounted for 28.8% (n = 124) of images from 29.9% (n = 46) of observations (Table 4.4).

The Lanner Falcon had 420 images from 196 observations classified as prey capture and handling did not differ significantly (Kruskal Wallis: H = 4.552, df = 5, p = 0.473, Table 4.5). From these posts/observations, primate prey accounted for 0.2% (n = 1) of images from 0.5% (n = 1) of observations; avian prey accounted for 69.5% (n = 292) of images from 72.5% (n = 142) of observations; insect prey accounted for 6.0% (n = 25) of images from 5.1% (n = 10) of observations; reptile prey accounted for 1.2% (n = 5) of images from 0.5% (n = 1) of observations; rodent prey accounted for 0.7% (n = 3) of images from 1.0% (n = 2) of observations; and unidentified prey accounted for 22.4% (n = 94) of images from 20.4% (n = 40) of observations.

Table 4.4: Summary of selected prey species observed from image posts/observations on social media in South Africa for the Peregrine Falcon up until the 31st of August 2024.

	Common name	Scientific name	No. of images	No. of observations
Avian	Alpine Swift	*Tachymarptis melba*	1	1
	Bee-eater	*Merops apiaster*	2	1
	Black Sparrowhawk	*Accipiter melanoleucus*	1	1
	Blacksmith Lapwing	*Vanellus armatus*	7	2
	Cape Weaver	*Ploceus capensis*	1	1
	Dove	*Columbidae*	30	12
	Laughing Dove	*Spilopelia senegalensis*	2	2
	Pied Starling	*Lamprotornis bicolor*	1	1
	Pigeon	*Columbidae*	37	10
	Quelea	*Ploceidae*	1	1
	Racing Pigeon	*Columba livia domestica*	2	1
	Red-eyed Dove	*Streptopelia semitorquata*	1	1
	Ring-necked Dove	*Streptopelia capicola*	5	3
	Rock Dove	*Columba livia*	13	3
	Spotted Dove	*Spilopelia chinensis*	2	1
	Speckled Mousebird	*Colius striatus*	4	1
	Speckled Pigeon	*Columba guinea*	15	4
	Storm Petrel	*Hydrobates pelagicus*	1	1
	Swallow	*Hirundinidae*	2	1
	Unidentified	-	158	55
	White-eared Barbet	*Stactolaema leucotis*	8	1
		Total	294	104
Chiroptera	Bat	*Chiroptera*	4	2
		Total	4	2
Insect	Unidentified	-	1	1
		Total	1	1
Reptile	Snake	*Ophidia*	7	1
		Total	7	1
Unidentified	Unidentified	-	124	46
		Total	124	46

Table 4.5: Summary of selected prey species observed from image posts/observations on social media in South Africa for the Lanner Falcon up until the 31st of August 2024.

	Common name	Scientific name	No. of images	No. of observations
Avian	Blacksmith Lapwing	*Vanellus armatus*	14	2
	Black-winged Pratincoles	*Glareola nordmanni*	1	1
	Burchell's Sandgrouse	*Pterocles burchelli*	10	5
	Ring-necked Dove	*Streptopelia capicola*	24	7
	Cattle Egret	*Bubulcus ibis*	2	1
	Dove	*Columbidae*	37	21
	Egret	*Ardeidae*	1	1
	Fork-tailed Drongo	*Dicrurus adsimilis*	2	2
	Grouse	*Tetraonidae*	15	1
	Helmeted Guineafowl	*Numida meleagris*	2	1
	Lark-like Bunting	*Emberiza impetuani*	1	1
	Mina Bird	*Acridotheres tristis*	4	1
	Namaqua Dove	*Oena capensis*	14	11
	Namaqua Sandgrouse	*Pterocles Namaqua*	1	1
	Pigeon	*Columbidae*	21	10
	Quelea	*Ploceidae*	4	2
	Red-billed Quelea	*Quelea quelea*	5	5
	Red-headed Finch	*Amadina erythrocephala*	9	4
	Reed Cormorant	*Microcarbo africanus*	3	1
	Rock Dove	*Columba livia*	12	3
	Southern Fiscal	*Lanius collaris*	3	1
	Sandgrouse	*Pteroclidae*	8	3
	Unidentified	-	99	57
		Total	292	142
Insect	Flying Ants	*Formicidae*	21	7
	Termites	*Isoptera*	2	2
	Toktokkie	*Psammodes striatus*	2	1
		Total	25	10
Reptile	Unidentified	-	5	1
		Total	5	1
Primate	Vervet monkey	*Chlorocebus pygerythrus*	1	1
		Total	1	1
Rodent	Mouse	*Muridae*	3	2
		Total	3	2
Unidentified	Unidentified	-	94	40
		Total	94	40

4.5 Discussion

This study examined observations/posts and images of Lanner Falcons and Peregrine Falcons from social media platforms (Facebook®, iNaturalist®, and eBird®s) to provide a broader understanding of these falcons in South Africa. Data shared by citizen scientists on social networks are a cost-effective and passive way to obtain information on biodiversity (Otero et al. 2024). The results from this study reinforce the value of social media platforms as a tool for data collection. The distribution of images and posts/observations and the geographic representation of these observations provide insight into the dynamics and ecological interactions of these species of falcons in the region. Peregrine Falcons were observed fewer times, resulting in fewer images than Lanner Falcons. This proportion of images and posts/observations highlights a higher frequency of observations/posts and subsequent images for Lanner Falcons compared with Peregrine Falcons, which may suggest a greater visibility or reporting rate of Lanner Falcons in some regions in South Africa. The disparity in observations between these falcons may reflect differences in their population sizes, distribution and movement, habitat preferences, or the visibility of these falcon species within the various environments/Provinces in South Africa. The high frequency of observations for the Lanner Falcon across South Africa may suggest that observers may more commonly encounter the species, potentially because of their persistence in rural and urban landscapes (Jenkins 1994; Jenkins 2000a; McPherson et al. 2021).

4.5.1 Social media overview

The three platforms selected were based on user interests for comparison. Facebook® attracts all users, iNaturalist® attracts users for fauna and flora, and eBird® attracts avian enthusiasts. The

results showed a notable pattern in recording and posting observations across the different platform sources. For Peregrine Falcons, Facebook® Sourced the most observations, followed by iNaturalist® and then eBird®. This trend also carried over to image observations, where Facebook® accounted for the largest contribution of observed images, indicating Facebook®s role as a prominent platform that can be used by researchers, academics, wildlife enthusiasts, bird monitors, and casual observers alike. Similarly, Chamberlain (2018) highlighted the usefulness of Facebook® for biomonitoring, using dedicated Facebook® groups for species of interest in data collection and the exchange of information.

Lanner Falcons showed a more balanced observation/post distribution across the three platforms in contracts. Facebook® accounted for the most observations, followed closely by iNaturalist® and then eBird®. The relative contribution of iNaturalist® and eBird®s for the Lanner Falcon, compared with the contributions of Facebook®, suggest that Facebook® can be used for more systematic observations when platforms are used effectively. Facebook has a vast global user base that can be used to supplement traditional monitoring methods and allows for real-time reporting/posting of observed wildlife interactions (Sullivan et al. 2019). However, collecting data from multiple sources would provide greater understanding and enhance data collection and reliability.

The variation in contributions from each platform also emphasises the importance of diversifying data collection sources to capture a more comprehensive view of targeted species' behaviour, interactions, distribution, movement, and presence. Similarly, Chowdhury et al. (2023b) showed that integrating existing biodiversity databases with Facebook® data can improve conservation planning for targeted species by identifying critical areas for protection. Additionally,

different platforms cater to different user demographics and motivations, and using the strengths from different platform sources effectively could enhance and improve observational data and ecological understanding overall. Facebook®, for example, has a vast and global user base, and although it was not intended for research, it can serve as a valuable tool for gathering observational data from a broad and diverse audience (Chamberlain 2018; Chowdhury et al. 2023b). The caveat, however, is that the potential for data quality and validation may vary when compared with more dedicated and specialised platforms like iNaturalist® and eBird®. The different platforms additionally attract different users; Facebook® users stem predominantly from its network and social features, whereas iNaturalist® and eBird® users are likely attracted to and interested in targeted species, biodiversity monitoring and ecological research as found in other studies (Nadkarni and Hofmann 2012; Sullivan et al. 2017; Unger et al. 2021). This can influence the reporting rate/observation of species when comparing different platforms because of the inclination of interested citizen scientists to post their observations on their preferred platform.

The number of users and frequency of use per platform may also affect the interest and frequency of posts/observations for these falcons. For both falcon species, Facebook® had the most observer contributions. Across the three platforms, Lanner Falcons had more observers, this may be because of their more restricted global distribution, being an Afro-tropical species, observers may be more inclined to post their observations within South Africa (Jenkins 2000a; Stephenson 2001). Additionally, for both falcon species, eBird® had the least observer contributions. This may reflect an aversion of users to more dedicated/restricted platforms that are species-specific, in this case, restricted to bird observations only, compared with platforms like

iNaturalist®, which are open to all fauna and flora. The lack of species restrictions allows current users who otherwise may not be interested in birds to be still able to post their observations.

4.5.2 Temporal analysis of observations

The date the observation was considered, instead of the date the observation was made, to prevent bias. Thus there were observations prior to the platform's launch; for example, Facebook® was launched in 2004, and the earliest observation was from 2011, but for eBird®, the platform started in 2002, but the earliest observation was from 1979 (Hei-Man 2008; Sullivan et al. 2014). Examination of the temporal distribution of observations from the three platforms reveals notable trends for both falcon species. Posts/observations of Peregrine Falcons were the least posted/observed p.a. before 2013, observations/posts increased p.a. from 2013 to 2018, and there was a further increase of observations/posts p.a. from 2018 onwards, contributing a considerable 75.4% of total observations for this species.

We found a similar trend with the observations/posts for the Lanner Falcon, with observations/posts before 2010 accounting for the least posts/observations p.a., indicating limitations in engagement with this falcon species in the earlier years. From 2010 to 2017, there was a substantial increase in observations/posts p.a. and from 2017 onwards, there was a further increase in posts/observations p.a., contributing to the majority of observations at 75.1% of total observations for this species.

The paralleled growth in trends for both falcon species may suggest a growing interest in avian monitoring (particularly for these falcons) and citizen science in South Africa with an increasing capacity for public engagement in data collection when using different platforms. The

increase in posts/observations may be because of the growing interest in birdwatching and the rise of citizen science platforms, thus actively facilitating an avenue for more significant reporting and documentation of selected local wildlife species as time progresses (Zhou et al. 2020; Janeczko et al. 2021). Post-2017, we found a considerable rise in posts/observations for both falcon species, with more observations for both species post-COVID-19 (2021-2024) compared with pre-COVID-19 (2017-2020), indicating more individuals are engaging with local ecosystems and wildlife, thus actively contributing valuable data by reporting and posting species sightings that can assist in conservation efforts. During the COVID-19 lockdown, Sun et al. (2024) showed that avian species reacted differently to the change in the presence of humans; the Hooded Crow, *Corvus corone cornix* (an urban exploiter) decreased their urban activities, whereas the Graceful Prinia, *Prinia gracilis*, (an urban adapter) increased their presence. Basile et al. (2021) noted an increase in urban observations and a decrease in non-urban observations from citizen science platforms during the lockdown, particularly in European countries. This further emphasises the need to understand the trends of wildlife sightings to develop targeted conservation strategies, update species status, and allocate potential resources to support threatened species. Furthermore, the observed differences in patterns from observations for the two falcon species may warrant further research within South Africa and globally. Factors such as nesting success, diet preferences, habitat preferences, distribution and movement, and responses to urbanisation could help explain the observed disparities.

4.5.3 Geographic distribution

The geographical distribution of images and posts/observations in South Africa revealed significant regional variation. Both falcons were observed/posted in all nine provinces of South Africa. Both species are widely distributed throughout sub-Saharan Africa (Jenkins and Avery 1999), which aligns with the results obtained in the present study. These overlap with their distribution ranges aligned with the data obtained by the South African Bird Atlas Project (SABAP 2024). Lanner Falcons were observed/posted more in most provinces (Eastern Cape, Free State, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, and the North West), excluding Gauteng and the Western Cape, where Peregrine Falcons had more observations/posts. Subsequently, most provinces had more images posted/observed with more observers of Lanner Falcons, excluding Gauteng and the Western Cape, where there were more images posted/observed with more observers for Peregrine Falcons. The Western Cape Province dominated image observations and posts/observations for the Peregrine Falcon, similar to the SABAP2 data (SABAP 2024) (Chapter 3).

In contrast, the Northern Cape Province was notable for the Lanner Falcon. The disparities in provincial representation may reflect differences in population densities between the falcons. KwaZulu-Natal and the Eastern Cape also showed a relatively high contribution for both species images and posts/observations, suggesting more active engagement in these areas regarding reporting/posting observations of these falcons. The lower representation in some provinces, such as in the North West and the Free State for both species, may indicate potential gaps in sightings, data collections, or lower populations of these falcons in these areas.

The geographic disparities in image observations and posts/observations indicate a need for targeted outreach in areas in South Africa that may be underrepresented. Engaging with local communities, bird enthusiasts, interested citizen scientists, and other avenues to encourage wildlife observations could enrich data collection efforts for these falcon species and provide a more comprehensive understanding of falcon behaviour and ecology across South Africa.

4.5.4 Observations based on behaviour

For the Peregrine Falcon, the predominantly noticed behaviour was resting behaviour (43.3%), followed by flight (31.7%), and then prey capture and handling (17.9%). This suggests that Peregrine Falcons are often observed in rest periods, which may reflect difficulty in sighting or photographing this species. Additionally, species like the Peregrine Falcon and Lanner Falcon can be difficult to observe because of their distribution, movement, flight speed, poor visibility, and preference for nesting landscapes (Jenkins 2000a; Mills et al. 2008; Ferrarini and Gustin 2022). Lanner Falcons display similar trends, with resting behaviour constituting the most observations (46.3%), closely followed by flight (32.4%). The prevalence of these behaviours suggests a commonality in the daily lives of these falcons. This is to be expected because of the similarities between the two species with respect to size, diet, nesting habitats and distribution within South Africa (Jenkins 1995; Jenkins and Avery 1999). However, the noticeably lower percentage of intraspecific and interspecific interactions in both falcon species may indicate potential limitations in social interactions, but this can also be attributed to low visibility or lack of observations for these behaviours. This may also be influenced by the environments/provinces in which these observations/posts were made. Ultimately, this may be because of a lack of observation and

difficulty sighting falcon species. The observed behavioural trends identified highlight the importance of monitoring and understanding the interactions between these falcons and their environments.

4.5.5 Intraspecific and interspecific interactions

From the observed intraspecific interactions, Peregrine Falcons exhibited a notable prevalence of positive interactions (68.3% of intraspecific interactions). This suggests a social structure that supports cooperative behaviours observed from images, such as parental care by feeding their young and playful interactions between familial members, as found in other studies (Ellis et al. 1993; Dekker and Taylor 2005; Negro and Galván 2018). This reflects social bonds within this falcon species, and these dynamics likely enhance survival and reproductive success. Similarly, Lanner Falcons also displayed mostly positive interactions (54.3% of intraspecific interactions). This was predominantly observed through courtship and mating behaviours, highlighting a similar social structure to Peregrine Falcons. Neutral interactions varied between the two species. Lanner Falcons displayed a higher proportion of neutral behaviours (32.9% of intraspecific interactions). The results indicate a tendency toward general interactions and communication that may not directly influence immediate social interactions (neither positive nor negative). The role of neutral behaviours and interactions warrants further research and monitoring to understand the implications within the social structures that exist for these falcons.

Conversely, negative interactions were more pronounced in Peregrine Falcon observations. Observations of aerial combat and bullying (mainly between fledglings) accounted for significant proportions of image observations. This may reflect social dominant interactions or the

competitive dynamics within these falcons' habitats, where resource limitations and territorial behaviour play critical roles in the dynamics between and among falcon species, as found in other studies (Jenkins and Hockey 2001; Brambilla et al. 2010; De Rosa et al. 2019). In contrast, Lanner Falcons had a lower observed incidence of negative interactions, particularly in bullying behaviour. This may suggest differing ecological pressures for this species or a more harmonious social dynamic in comparison, but is likely because of a lack of observations for this behaviour.

From the observed interspecific interactions, both falcons displayed aggressive tendencies towards other species, with Lanner Falcons displaying slightly more observed aggressive acts. This suggests that both falcon species display a more proactive approach in defending their territories or resources, which may be necessary in environments where interspecific competition is fierce, and resources are limited (Stephenson 2001; Brambilla et al. 2010; Leonardi and Leonardi 2020). Both falcon species had a relatively equal distribution of neutral interactions (40.4% for Peregrine Falcons and 31.8% for Lanner Falcons interspecific interactions). This implies that both falcons can and do engage in a significant amount of non-aggressive encounters with other species; this may facilitate the coexistence of both falcon species in areas of co-occurrence where competition is not necessary. Both species had defensive responses observed, which indicates that both species face threats from other species. However, the observed aggressive interactions from both falcon species were higher than their observed defensive interactions, suggesting that both species are more dominant in the habitats in which they occur. This may indicate a dominance hierarchy in their interactions with other avian species that share their habitat, but further monitoring is recommended.

4.5.6 Prey capture and handling

The results show that avian prey constituted the majority of observed prey for both falcon species, accounting for 68.4% (n = 294) of images from 67.5% (n = 104) of observations. This suggests that Peregrine Falcons primarily target other birds as prey, which reflects their preference for prey selection or an opportunistic diet (Sutton et al. 2017; Dixon and Drewitt 2018; Janžekovič et al. 2018; Obuch and Chavko 2022).

In contrast, Lanner Falcons revealed 420 images from 196 posts/observations. The results also show that avian prey constituted the majority of observed prey, accounting for 69.5% (n=292) of images from 72.5% (n = 142) of observations (Kemp 1993; Jenkins and Avery 1999). This parallel showing a preference for avian prey from observed images among both species of falcons could indicate competition for similar food resources or overlap in dietary selection within shared ecological niches within their habitats. Jenkins and Avery (1999) showed a 35% overlap in diet when these falcons are sympatric, but this may need to be reevaluated for present dynamics. For Peregrine Falcons, avian prey was predominantly observed; however, other species such as Chiroptera, insects, and reptiles were also observed but were minimal in comparison. The lower frequency of non-avian prey types may suggest that Peregrine Falcons are less likely to pursue diverse prey sources, aligning with their general foraging behaviour and diet preferences within urban environments, preferring avian prey (Dixon and Drewitt 2018; Janžekovič et al. 2018). This further shows that Peregrine Falcons are opportunistic generalists with a preference for avian prey (Stevens et al. 2009).

In contrast, Lanner Falcons displayed a more varied prey composition, such as insects, rodents, and reptile prey. This indicates a broader foraging strategy, suggesting opportunistic

hunting behaviour, potentially reflecting Lanner Falcons' behavioural plasticity to different habitats and prey availability (Jenkins 1998; Jenkins and Avery 1999). Lanner Falcons also have a preference for avian prey but display a more varied diet in comparison, displaying opportunistic generalist behaviour (Stephenson 2001). Notably, there is a high proportion of unidentified prey from both falcons' image prey identification. For Peregrine Falcons, 28.8% of images from 29.9% of observations fell into this category. Similarly, for Lanner Falcons, 22.4% of images from 20.4% of observations were also unidentified prey. Prey identification was based on observer accounts or based on the comments of the observations to remove any bias in identification from the author. This highlights potential gaps in identification skills or reporting additional information (like prey, location, and date of observations) among observers and citizen scientists. This may also be because of the rapid nature of predation events of both falcons, making it challenging to accurately identify selected prey.

4.5.7 Conclusions

In conclusion, our study provides a foundational overview of Peregrine and Lanner Falcon's observed behaviour, diet, social interactions, and distribution from posts/observations on social media platforms and the temporal distribution of those posts/observations across South Africa. These findings offer valuable insights for ecologists, conservationists, animal behaviourists, and other interested parties, further emphasising the usefulness of citizen science. The conclusions of this study highlight the usefulness of using multiple platforms, including different social media platforms, for wildlife observation. The significant rise in observations throughout the years for both falcon species suggests a positive trend not only in public interest and ecological awareness

for these falcons in South Africa, but also in the status of these falcon species. By fostering public engagement and participation in conjunction with regular, more commonly used data collection methods, we can enhance our knowledge and understanding of these falcons and contribute to their conservation and preservation in South Africa. Observing both falcons' prey capture and handling behaviours revealed insights into both species' dietary preferences and versatility in prey selection.

Additionally, the differences in images and post/observation contributions between Peregrine Falcons and Lanner Falcons highlight varying levels of visibility and engagement for reporting sightings among the different platforms for both species. Using citizen science platforms like iNaturalist®, eBird®, and Facebook®, for data collection can be limited by issues such as user-reporting bias, lack of verification, lack of accurate identification, lack of contextual information when reporting/posting, and issues with data accuracy. An example of sample bias in the data was the high percentage of observations from the Northern Cape (34.7%), likely driven by frequent sightings of Lanner Falcons in the Kgalagadi, where artificial waterholes attract considerable attention and this resulted in a disproportionate number of photographs from that province (various pers. comm.). Future research can focus on optimising data collection strategies across multiple platforms in conjunction with regular data collection methods (like surveys, observations, censuses) to ensure citizen scientists can effectively contribute to our understanding of these species of falcons' dynamics in South Africa. Training is recommended for citizen scientists to ensure accurate observations, reporting sightings, and encouraging public participation across multiple platforms to improve data quality and increase awareness of these falcons globally. This will ultimately improve conservation initiatives, contribute to knowledge

gaps, improve status assignments, passively track movement and distribution, and enhance our understanding of these falcons' ecological interactions.

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4.8 Supplementary Information

Supplementary Information Table S4.1. Facebook group names and contribution to falcon observations

Group	Falcon Species	Posts/Observations
Bird's of South Africa	Peregrine Falcon	yes
	Lanner Falcon	none
Wildlife South Africa	Peregrine Falcon	none
	Lanner Falcon	none
BirdLife South Africa	Peregrine Falcon	yes
	Lanner Falcon	yes
African Bird Club community	Peregrine Falcon	yes
	Lanner Falcon	yes
Raptors of Southern Africa	Peregrine Falcon	yes
	Lanner Falcon	yes
Southern Africa Birding	Peregrine Falcon	yes
	Lanner Falcon	yes
SA birds, birders and birding	Peregrine Falcon	none
	Lanner Falcon	none
Bird Photography South Africa	Peregrine Falcon	none
	Lanner Falcon	yes
South African Birds	Peregrine Falcon	yes
	Lanner Falcon	yes
Let's Go Birding South Africa	Peregrine Falcon	yes
	Lanner Falcon	yes
Birds & Wildlife Of Southern Africa	Peregrine Falcon	none
	Lanner Falcon	none
S.A. BIRDERS CLUB	Peregrine Falcon	yes
	Lanner Falcon	yes
African Wildlife Photography	Peregrine Falcon	none
	Lanner Falcon	yes
Bird Photographers of Southern Africa	Peregrine Falcon	yes
	Lanner Falcon	yes
BirdLife KZN Midlands	Peregrine Falcon	yes
	Lanner Falcon	yes
Simply Birding Africa	Peregrine Falcon	yes
	Lanner Falcon	yes
Birding in Africa	Peregrine Falcon	yes
	Lanner Falcon	yes
Colourful Birds of Southern Africa	Peregrine Falcon	yes

	Lanner Falcon	yes
Birds of Southern Africa	Peregrine Falcon	none
	Lanner Falcon	none
Migratory Birds of Southern Africa	Peregrine Falcon	none
	Lanner Falcon	none
Birdlife in KwaZulu-Natal	Peregrine Falcon	yes
	Lanner Falcon	yes
Western Cape Birders	Peregrine Falcon	yes
	Lanner Falcon	yes
Birds of Africa	Peregrine Falcon	yes
	Lanner Falcon	none
BirdLife Northern Gauteng - BLNG	Peregrine Falcon	yes
	Lanner Falcon	yes
Birds of Southern KZN	Peregrine Falcon	Blocked
	Lanner Falcon	Blocked
Birds of Zululand - KZN	Peregrine Falcon	yes
	Lanner Falcon	yes
Birdlife Zululand	Peregrine Falcon	yes
	Lanner Falcon	yes
Garden Route Birds - Share Your Birds!	Peregrine Falcon	yes
	Lanner Falcon	yes
Birds and Animals of The Kruger National Park	Peregrine Falcon	none
	Lanner Falcon	none
Eastern Cape Birding	Peregrine Falcon	yes
	Lanner Falcon	yes
The Birding Life Community	Peregrine Falcon	yes
	Lanner Falcon	yes
Garden Route & Klein Karoo Birding	Peregrine Falcon	yes
	Lanner Falcon	yes
SA Rare Birds	Peregrine Falcon	yes
	Lanner Falcon	yes
BirdLife Lowveld.	Peregrine Falcon	yes
	Lanner Falcon	yes
Birding Group - Cape Town	Peregrine Falcon	none
	Lanner Falcon	none
Birdlife Rustenburg	Peregrine Falcon	yes
	Lanner Falcon	yes
Witwatersrand Bird Club	Peregrine Falcon	yes

	Lanner Falcon	yes
Zaagkuilsdrift & Kgomo-Kgomo Birding	Peregrine Falcon Lanner Falcon	none none
Limpopo Birding	Peregrine Falcon Lanner Falcon	none none
SANParks - Karoo National Park	Peregrine Falcon Lanner Falcon	none none
BirdLife Northern Newcastle	Peregrine Falcon Lanner Falcon	yes yes
BirdLife Eastern Cape (BLEC)	Peregrine Falcon Lanner Falcon	yes yes
BirdLife Free state	Peregrine Falcon Lanner Falcon	none yes

CHAPTER 5

General discussion, conclusions and recommendations

5.1 Background

Africa has one of the highest rates of human population growth and urbanisation; however, the impacts on biodiversity remain largely understudied (Potts 2012; Sumasgutner et al. 2020). The importance of urban ecology has become more relevant in understanding and creating a mutualistic supportive ecosystem for both urbanised human populations and wildlife (Lowry et al. 2013; McPherson et al. 2021). One of the significant threats affecting raptors in South Africa is the rapid expansion of the human population present. This has altered the landscape's functioning and capacity to support wildlife, particularly raptors and their prey, but some species have adapted to use resources within city boundaries (McPherson et al. 2021; Downs et al. 2021). Raptors are also highly responsive to climate change because of the impacts it has on their population's range distribution, species richness, population densities, migratory patterns, and reproductive performance, including productivity, incubation behaviour, and hatching success (Jaffré et al. 2013; Kettle et al. 2018; Sarà et al. 2022; Foysal and Panter 2024). Most raptors are long-lived territorial species and show consistency in the areas they breed, with the habitat around their nesting areas and features associated with the area contributing greatly to the breeding success and fitness of the species (Sarà et al. 2016; Kettle et al. 2018).

Sixty-six raptor species have been recorded in urban areas of South Africa, but only a few of these species have been adequately studied despite raptors falling under a high level of conservational concern (McPherson et al. 2021; Sarà et al. 2022). The two raptor species that were the focus of this study are the Peregrine Falcon (*Falco peregrinus*) and the Lanner Falcon (*F.*

biarmicus), which have been shown to occur sympatrically throughout sub-Saharan Africa (Jenkins and Avery 1999; Jenkins 2000). South Africa has a rich biodiversity, and thus, the effects of climate change, population growth, and urbanisation will be particularly severe on displaced raptors like the Peregrine and Lanner Falcons that had to adapt and display behavioural plasticity to live in urban areas (Sumasgutner et al. 2020; McPherson et al. 2021). Knowledge gaps still exist regarding urban raptors in Africa, and urban raptor research has focussed more on North America and Europe, requiring further research to be conducted in different areas worldwide, and in South Africa in particular (McPherson et al. 2021). Africa and Asia are two of the fastest regions in the world for urban expansion; however, comprehensive studies on the ecological effects on vulnerable species, like these falcons, remain understudied (Sumasgutner et al. 2020). The loss of key apex raptor predators like these two falcons can have cascading effects at an ecosystem level and can further contribute to global biodiversity loss because of climate change, land use changes, and urbanisation (Sumasgutner et al. 2020; Foysal and Panter 2024). Understanding ecological interactions is necessary to implement conservation planning and management for endangered or protected species (Sarà et al. 2016).

Both these raptors are small to medium in size, have the same distribution throughout sub-Saharan Africa, have similar food requirements, and have similar basic habitat requirements (Jenkins 1995; Hart et al. 2018). The Lanner Falcon and Peregrine Falcon generally co-occur in regions with overlapping distributions, and are morphologically very similar species, and since they also have an overlap in their diets, competitive exclusion may occur (Sarà et al. 2016). These two raptor species have different breeding times and use diverse cliff substrates in their breeding activities, which implies a coexistence between the two falcon species, and observations in South

Africa suggest these falcons are not active competitors (Jenkins 2000b; Sarà et al. 2016). However, these two species' habitats are threatened by urbanisation, land use changes, and population growth, which results in these falcon species adapting to live and nest in urban areas, which may lead to competition. Additionally, urbanisation can alter the local climate, which generally negatively impacts avian species as most species' temporal and spatial distribution are driven by climate (Sumasgutner et al. 2020). Raptors are also highly responsive to climate change as it impacts their populations' ecology and dynamics, which further emphasises the need for ecological studies (Sarà et al. 2022; Foysal and Panter 2024). Despite this, some raptor species persist in urban mosaic landscapes.

5.2 Summary of findings

5.2.1 State of research

This systematic review examined global literature on the Peregrine Falcon and Lanner Falcon to highlight trends in research and gather insights on aspects that can be prioritised for future studies (Chapter 2). Research aligned with both species' distribution ranges. Peregrine Falcons were researched more frequently with a bias towards European and North American populations, and European populations for Lanner Falcons. Research methods for studying these falcons primarily used observations/descriptive and biological and genetic sampling for data collection, and other methods remain underutilised comparatively. The leading research for Lanner Falcons covered breeding, health and environmental stressors, and habitat; however, this species remains understudied. To improve this species understanding, research topics can cover genetics and taxonomy, interspecific interactions, intraspecific interactions, and movement. The main research

topics for Peregrine Falcons were breeding, conservation, health and environmental stressors, and population ecology and demography. The least covered research topics were abundance, genetics and taxonomy, interspecific interactions, intraspecific interactions, and movement; however, this species is adequately studied in comparison (Chapter 2). More research is recommended to cover geographical regions of their distribution that remain understudied, particularly for Lanner Falcons, using multiple data collection methods.

5.2.2 Distribution trends across South Africa

Data from the Southern African Bird Atlas Project (SABAP) were used to investigate the distribution and relative abundance of Peregrine Falcons and Lanner Falcons across South Africa, Lesotho, and Eswatini, and to detect changes in distribution patterns and abundance over time (Chapter 3). There was a notable increase in Peregrine Falcon reporting rates, particularly in urban areas, suggesting successful adaptation to anthropogenic landscapes. In contrast, Lanner Falcons displayed a more varied pattern, with some regions showing declines, especially where Peregrine Falcons were more prevalent, potentially indicating competitive displacement mediated by urbanisation (Chapter 3). These findings underscore the complex interplay between urbanisation, species competition, and habitat preferences in shaping these raptors' distribution and population trends. While the behavioural plasticity of the Peregrine Falcon to urban environments highlights its resilience, the mixed responses of the Lanner Falcon suggest targeted conservation strategies to mitigate the impacts of habitat fragmentation and urban encroachment. This study's use of citizen science data illustrates its value in long-term ecological monitoring and its potential for informing conservation efforts (Chapter 3).

5.2.3 Social media observations in South Africa

This chapter provides a foundational overview of Peregrine and Lanner Falcon's observed behaviour from posts/observations on social media and the distribution and timeline of those posts/observations across South Africa (Chapter 4). This study highlighted the usefulness of using multiple platforms, including social media networks, for wildlife observation to generate insight into the distribution, and ecological interactions of Peregrine Falcons and Lanner Falcons in South Africa. Post-2017, there was a significant rise in posts/observations for both falcon species. Both falcons were observed in all nine provinces of South Africa. The differences in images and post/observation contributions of Peregrine Falcons and Lanner Falcons highlighted varying levels of visibility and engagement for reporting sightings among the different species and behaviours of the two species (Chapter 4). The significant rise in observations throughout the years for both falcon species suggests a positive trend in public interest and ecological awareness for these falcons in South Africa (Chapter 4).

5.3 Conclusions

The research conducted in this thesis provides novel information on Peregrine Falcons and Lanner Falcons' ecology, distribution, urban persistence, behavioural plasticity, and state of research in South Africa. Peregrine Falcons are more widely distributed globally and thus have more research than Lanner Falcons, which remain understudied. However, in South Africa, where the species co-occur, Lanner Falcons were more frequently observed, but both species remained understudied, but the Lanner Falcon was more so in comparison. Research on both falcons focussed on their

breeding ecology and the health of the species with a focus on egg-shell thickness in response to environmental factors and parasitic studies. Although the Peregrine Falcon is adequately studied in comparison, both species remain understudied in their geographical distributions (excluding Europe and North America). Research techniques for monitoring and data collection relied on observational data such as surveys, census, and fieldwork, as well as biological and genetic sampling such as DNA extraction and analysis of prey remains. Established monitoring techniques are commonly used, and new novel approaches such as citizen science remain underutilised but with growing interest.

By examining the distribution of Peregrine Falcons and Lanner Falcons across South Africa, there have been some changes in distribution ranges, although not extreme. The colonisation of new areas is suggested to result from urbanisation and anthropogenic development expanding into areas or close to areas where these falcons reside.

Peregrine Falcons had a more restricted distribution within South Africa than Lanner Falcons, and both species had distributions within urban areas. Peregrine Falcons seem more tolerant of urban areas but maintain higher species richness within more natural environments. Lanner Falcons displayed mixed trends in different regions for the distribution but appear to be less tolerant to urban areas in comparison, particularly in areas where Peregrine Falcons were present. The presence of Lanner Falcons did not negatively influence Peregrine Falcons distributions. The increased presence in some urban areas within the context of South Africa, and to a larger extent globally, maybe a response to urban expansion infringing on these falcons' natural habitats instead of increases in population numbers.

5.4 Recommendations

The persistence of two raptors, the Peregrine Falcon and the Lanner Falcon, in urban mosaic landscapes, particularly in regions of their distribution that remain understudied, such as South Africa, is recommended to be investigated. In particular, their presence, ecology, and breeding success in urban areas should be assessed.

Lanner Falcons are more widely distributed because they are less macrohabitat-specific than Peregrine Falcons (Jenkins 2000a). These falcons feed on smaller birds caught during ariel chases, with Lanner Falcons being more of a generalised feeder (Jenkins 1995; Jenkins and Avery 1999). They require open habitats for hunting and exhibiting territorial behaviour (Jenkins 2000b; De Rosa et al. 2019). Peregrine and Lanner Falcons have adapted to use resources within the city boundaries, but their persistence remains understudied (McPherson et al. 2021). In urban areas, the falcons' prey includes feral pigeons (*Columba livia domestica*), which foul buildings and carry disease, causing environmental and economic concerns. Thus, promoting the success of these falcons within urban areas can act as a biological control for pest species like feral pigeons.

Peregrine and Lanner Falcons will not typically build nesting structures; instead, they breed on cliffs, stick nests constructed by other avian species, or flattened surface ledges (Jenkins 2000a,b; Mak et al. 2021). Artificial nest boxes can be used as a monitoring system for falcons in urban areas. They can be used for conservation efforts and to protect threatened or endangered avian species. The nesting habitat selection and quality influence the breeding success of these falcons, with the physical features of a nest site protecting the falcons and their offspring; thus, using artificial nesting boxes provides the falcons with an improved opportunity for reproductive success in their displaced habitats (Jenkins 2000a). In addition, the falcons' provisioning services

can be monitored based on prey brought to the nesting sites, especially artificial ones (Jenkins 2000a). Urban-breeding falcon species prefer locations on buildings that are sheltered simulating an urban equivalent to steep cliffs, in particular artificially provided nest boxes, over other nesting locations (Sumasgutner et al. 2020; Mak et al. 2021). They generally display earlier egg-laying, higher territorial behaviour, and higher productivity at these artificial nest sites (Altwegg et al. 2014; Sumasgutner et al. 2020). Nest boxes also provide a different micro-climate than natural nests and can be more hospitable and protective for falcons. Consequently, nest boxes can be used as conservation tools. Thus, these two falcons' persistence and breeding success in urban areas can be monitored using artificial nesting boxes and camera traps.

Monitoring if Peregrine Falcons displace Lanner Falcons from nesting sites is also recommended. According to niche theory, species that coexist should differ in their morphological, behavioural, or ecological characteristics to reduce their competition (Sarà et al. 2016). However, Peregrine Falcons have shown an increasing tendency to replace Lanner Falcons at breeding sites, which is suggested to be the main cause of the reduction of the distribution of Lanner Falcons (Sarà et al. 2016; Hart et al. 2018; De Rosa et al. 2019;). It is predicted that an increase in Peregrine Falcons will decrease the number of Lanner Falcons because of competitive exclusion and access to resources rather than environmental factors (De Rosa et al. 2019). Future research can aim to investigate this occurrence, particularly in urban areas.

5.5 References

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