ASSESSING HOW BIRD DIVERSITY OF URBAN GOLF COURSES IS INFLUENCED BY COURSE AND LANDSCAPE CONNECTIVITY

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Abstract

With increasing urbanisation and corresponding environmental impacts, urban green infrastructure (UGI) and the services it provides are of high importance. However, the degree to which these spaces are beneficial and provide ecological services are influenced by the extent to which patches of UGI are connected to each other. Varying levels of connectivity may enhance or lower the resilience of the UGI and the biodiversity it houses. Although not considered as UGI, golf courses are prominent green spaces in many urban landscapes occupying vast areas of land, and therefore hold potential to aid biodiversity and facilitate species movement. However, the extent which golf courses are able to do so is a function of both the structure and availability of resources on the golf courses, as well as in the surroundings areas or landscape in which they are situated . This notion of connectivity of golf courses to their surroundings UGI (in its many forms) and landscapes has not been adequately explored in the literature as much of the present literature has addressed golf courses' biodiversity in isolation of other UGI, or where it has been considered, only the context in which golf courses were situated has been acknowledged (i.e. urban or rural landscapes). Moreover, as golf courses occupy large areas of lands forms of UGI, they may also be able to enhance the connectivity of the landscapes in which they are situated through increasing land cover, and lowering fragmentation through connecting patches. This however, is also context specific, as seen in natural settings were golf courses would in fact fragment the landscape

This study therefore sought to assess the extent to which urban golf courses are connected to other forms of UGI in the South African context, and illustrate the importance of paying attention to connectivity in an avifaunal diversity study. It also aimed to investigate the potential of urban golf courses to foster avifaunal diversity in comparison to a reference landscape, the direct surrounding urban and residential areas. To analyse the extent to which golf courses in three South African cities were connected to the wider landscape a connectivity analysis was undertaken using GIS software. This analysis indicated that all golf courses were to some extent connected to a range of different UGI. Whilst the level of connectivity fluctuated between golf courses and cities, there was however no significant difference noted. Urban golf courses in the South African context are thus not isolated habitats but connected to other land uses and therefore potentially provide valuable resources that aid biodiversity. Despite being physically connected to surrounding UGI illustrating that both the golf courses benefit from the surrounding UGI and vice versa, at a larger landscape there was not sufficient evidence of the ability of golf courses to enhance connectivity.

Although there was little evidence of golf courses' ability to aid connectivity at the larger landscape scale, the observed extent to which golf courses were connected to their directly surrounding landscape and the high presence UGI within the larger landscape, informed the more refined investigation of avian biodiversity of golf courses in comparison to surrounding urban areas in the city of Cape Town. This biodiversity analysis indicated that there was significantly higher bird diversity on golf courses in comparison to the surrounding urban areas. However, the high level of connectivity to directly surrounding UGI that was obtained in the former part of the study proved to have no impact on the diversity noted. In contrast, the connectivity at the landscape scale, a scale addressing the broader landscape, provided valuable insight into factors determining the levels of avifaunal diversity noted.

This dissertation therefore provides evidence of the biodiversity supporting function of urban golf courses and highlights the importance of landscape context in ecological assessment. These findings are a starting point for future research about the capacity of golf courses to support biodiversity in conjunction with other UGI. In the Global South context, which is complex and dynamic in nature, this information is vital, as these dynamic and changing landscapes provide opportunities to incorporate, and preserve already existing biodiversity.

Key Words: Avifauna, biodiversity, connectivity, golf course, urban green infrastructure, urban ecology, South Africa

Declaration

By submitting this thesis/dissertation electronically, I declare that the entirety of the work contained therein is my own original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Rhodes University will not infringe any third - party rights, and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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List of abbreviations

ANOVA: Analysis of Variance

COGTA: Cooperative Governance and Traditional Affairs

DBH: Diameter at Breast Height

CSIR: Council for Scientific and Industrial Research

GIS: Geographical Information Systems

GPS: Global Positioning System

LecoS: Landscape Ecology Statistics

PCA: Principal Component Analysis

QGIS: Quantum Geographical Information Systems

SA: South Africa

SANBI: South African National Bioinformatics Institute

SANLC: South African National Land Cover

SANParks: South African National Parks

Stats SA: Statistics South Africa

TMNP: Table Mountain National Park

UGI: Urban Green Infrastructure

VCP: Variable Circular Plot

WHO: World Health Organisation

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Chapter 1: Introduction

1.1 Urban green infrastructure (UGI) and biodiversity

The modification of natural environments globally, a prominent cause of biodiversity loss, is closely linked to urbanisation and land use change (Nooten *et al.,* 2018). It is expected that almost 60 % of the Global South population will be living in urban areas by 2030 as compared to the 40 % that was present at the end of the 20th century (Zhang, 2016). Urbanisation at these rates not only has implications for the environment as it causes fragmentation, land use change, and biodiversity loss, but also for society due to pressures placed on resources. In some contexts this causes overcrowding, sanitation issues, and decreased wellbeing (Godfrey and Julien, 2005; Kondratyeva *et al.,* 2020).

Other notable implications of urbanisation for biodiversity include functional homogenisation and decreasing phylogenetic diversity (Kondratyeva *et al.,* 2020). These are of particular concern as functional homogenisation has further consequences for how species adapt to change, as seen in urban contexts (Kondratyeva *et al.,* 2020). Moreover, various meta-analyses illustrate a relationship between urbanisation and harms to biodiversity, abundance, and species richness of terrestrial animals (Batary *et al.,* 2017, Faeth *et al.,* 2011, Fenoglio *et al.,* 2020). However, there are variations between taxa, with birds, often a key indicator group, typically increasing in abundance, although their diversity and evenness generally decrease (Faeth *et al.,* 2011). Furthermore, factors determining species assemblages, stochasticity, facilitation, competition, and adaptation, are also usually altered negatively by urbanisation (Kondratyeva *et al.,* 2020).

Global South countries are experiencing some of the highest rates of urbanisation, and therefore it is important to consider the consequences of this process in these contexts. These countries house some of the most vulnerable populations of people as well as most global biodiversity hotspots (du Toit *et al.,* 2021; Parnell and Walawege, 2011; Robertson *et al.,* 2013; Shackleton *et al.,* 2021). Africa, a continent characterised by high levels of poverty and inequality, has the highest rate of urbanisation due to population growth alone, exacerbating many of the aforementioned effects of urbanisation and placing huge pressures on the environment (Parnell and Walawege, 2011; Tacoli *et al.,* 2015). In South Africa, Collinson *et al.* (2007) note the impact of the post-apartheid rural-to-urban migration as an additional driver of urban population growth. This shift, largely due to opportunities found in urban areas, continues to add to the rate of urbanisation in South Africa (Collinson *et al.,* 2007).

According to Parnell and Walawege (2011), these South African (and African) cities, many of which are coastal, will be the locations where the greatest global environmental change will take place, due to population growth. This prediction is concerning as the location of these cities (in coastal regions and riparian zones) makes them important in supporting high levels of biodiversity, and environmental shifts, therefore, have profound implications for biodiversity (Myers, 2021). For instance, one especially significant coastal city is Cape Town in the Western Cape of South Africa which houses the Cape Floristic region, boasting more than 9 000 species of vascular plants (Goldblatt *et al.,* 2005) and species-level endemism of approximately 69 % (Linder, 2003).

Aside from its intrinsic value, there are various instrumental reasons for the conservation of biodiversity in Global South cities. Here, the reliance on provisioning services from ecosystems is greater than in the North, highlighting the direct human and physical benefits derived from biodiverse ecosystems (Shackleton, 2021). This high reliance on the natural environment for provisioning services further indicates its importance for health, sanitation, and wellbeing. Nearly all of the 27 % of the global population that does not have access to piped water live in the Global South, and therefore need to rely on natural ecosystems for access to fresh water (Shackleton, 2021). In addition, health and wellbeing are also enhanced through cleaner, cooler, and non-toxic environments, which is what regulating ecosystem services achieves (Escobedo, 2021). Other reasons for the conservation of the natural world and green spaces relate to societal and cultural values (Aronson *et al.,* 2017).

Important within urban settings are green spaces and urban green infrastructure (UGI). Green spaces are often viewed by people in various and complex ways due to the different values of society (Lepczyk *et al.,* 2017). This is particularly evident in the Global South, which comprises diverse cultural and religious communities, with many people also relying strongly on natural resources for day-to-day living (Shackleton, 2021). Many cultures have significant ties and links to the natural world and thus would have different values allocated to blue (rivers, oceans, seas, and lakes) and green (forests, parks, grasslands, and recreational) spaces (Shackleton *et al.,* 2021). In contrast, many associate urban vegetation with crime, and thus in turn would see green spaces in a negative light (Davoren and Shackleton, 2021). These contrasting values are not unique to the Global South, but can be found between communities, suburbs, and areas in all parts of the world.

An increased understanding of the benefits of UGI allows for greater comprehension of its value (Chen *et al.,* 2021). However, it is often difficult to fully ascertain the value of an area, as the uses and users of UGI constantly change, along with their views and assigned values (Chen *et al.,* 2021). Furthermore, the interplay between certain environmental factors that promote biodiversity differs at different spatial scales, changing the role and the value of green spaces to an ecosystem and society (Nooten *et al.,* 2018). This is seen in how environmental factors, not limited to the urban landscape, such as climate, soil type and quality and rainfall are the most prominent variables shaping biodiversity at a landscape scale (Sala *et al.,* 2000), whilst at a local scale factors such as air quality, connectivity, land use and size and distribution of native habitat fragments are significant drivers (Beninde *et al.,* 2015; Nooten *et al.,* 2018). Furthermore, as noted by Adler and Jedicke (2022) and Morelli *et al.* (2018) some species (birds) respond differently to variables at different scales. There is therefore a substantial interplay between various environmental factors at different scales, which is important to consider when attempting to conserve biodiversity in urban spaces. Different climates, species, management strategies, social perceptions, and cultural norms indicate that measures aimed at the conservation and enhancement of biodiversity in natural environments would require sensitivity to context.

1.2 Golf courses as a component of UGI

Although not considered UGI, golf courses are prominent green spaces in many urban landscapes (Sandberg *et al.,* 2016). The game of golf takes place on a specially designed course. Over time, the style of courses has changed with the shift from the first coastal courses in Scotland to more inland courses (Keiser University College of Golf, n.d). These first courses, unique to coastal areas, are more commonly known as links or link courses and are characterised by their open layout and sparse vegetation (mostly made up of tall sea grasses) (Leading Courses, 2020). Additionally, link courses were initially classed as such due to the linking fashion of the 18 holes (Leading Courses, 2020). Over time, the style and shape of golf courses transformed relative to their location, as more courses were constructed in inland areas with more vegetation, especially trees (Keiser University College of Golf, n.d). Thus, their design has become comparable to the traditional urban park due to the incorporation of trees and other forms of vegetation, waterbodies and grasses, and consequently are termed parkland courses (Leading Courses, 2020). Parkland courses usually have high levels of architectural design and manicuring, and tend to be relatively flat (Leading Courses, 2020).

Although comparable to a traditional urban park, often associated with high levels of biodiversity and ecosystem services, golf courses are frequently portrayed as providing ecological and social disservices. For example, golf courses consume vast amounts of water, transform large areas of land, use many chemicals, and often house a range of non-native plant species that may be harmful to local ecosystems (Cai *et al.,* 2002; Guzmán and Fernández, 2014; Tanner and Gange, 2005). Additionally, socio-political concerns about golf courses include the exclusion of some individuals due to high tariffs, levels of inequality and physically fenced out (Spocter, 2017). In opposition to the growing prevalence of golf courses, Platt (1994) recalls a farmer saying 'You can eat vegetables, but you can't eat golf balls', addressing how golf courses across the world are making use of farmlands, forests and excessive water for their establishment and maintenance, at the expense of other land uses. This argument is even more cogent in the Global South which is characterised by higher levels of rapid urban growth, inequality, poverty and informality, where many more people live precarious lives (Parnell and Walawege, 2011; Tacoli *et al.,* 2015).

In South Africa, a Global South country, contestation about the large land area of golf courses exists due to their stark contrast to neighbouring, highly populated informal settlements, triggering debates around appropriate land use and distribution (Spocter, 2017). For example, controversy surrounds one golf course in Cape Town as a result of its 10-year lease agreement with the City of Cape Town, in that it was proposed for the course to be leased for less than R1 000 per month in an affluent, and generally expensive area of the city (Kretzmann and Luhanga, 2020). This information came to light at a time when forced removals were taking place in townships and informal settlements, starkly illustrating the spatial inequality of Cape Town, and the potential of golf courses to exacerbate these social ills (Horber, 2021).

In a different case study of the River Club golf course situated in Cape Town, the Amazon-run Development Project proposes to develop the course into housing, retail and office spaces (Horber, 2021). Concerns associated with this development relate to the fact that it will continue to cater towards high-income groups as housing will be targeted towards upper- and middle-income households. Moreover, the area on which the golf course is currently situated houses a Khoi San heritage site, which the proposed project proposes to flatten. The River Club is also situated on the Liesbeek and Black Rivers as well as the Raapenberg Wetlands, supporting a wide range of bird species (Horber, 2021). Not only will the construction lower the size and area of the combined and connected green space that supports these birds, but it will also directly impact their habitat by filling in part of the river and changing its dynamics. Golf courses in the Global South, therefore, remain controversial for environmental, political and socioeconomic reasons. However, according to Gange *et al.* (2003), golf courses may be misunderstood or underestimated in terms of their contribution to urban biodiversity. This misunderstanding is because their typically large size means that they potentially contribute significantly to UGI (spatially as a whole), and may have a positive impact on biodiversity (Nooten *et al.,* 2018). According to Worster (2008), a single golf course generally covers between 50 and 60 ha. Sandberg *et al.* (2016) suggest that this required area ranges between 50 and 100 ha.

Globally, golf course cover is approximately 1.9 to 2.3 million ha of land (Alkier *et al.,* 2020). Despite this already large area, there are another 534 courses under development with 53 proposed for construction in Africa (Alkier *et al.,* 2020). Despite this large area of land transformation and areas of exclusion, golf courses also house various green and natural elements. In addition, various elements of golf courses, such as the presence of water bodies, trees (and canopy cover), and in some cases connectivity to other UGI, are evident. Such elements often contribute to higher levels of biodiversity on golf courses than in other areas such as old agricultural lands (Tanner and Gange, 2005), or research indicating that golf course features may support biodiversity in general (Saarikivi *et al*., 2013).

Colding and Folke's (2009) quantitative synthesis of studies that compare biota on golf courses to that in surrounding landscapes indicates that golf courses have a higher ecological value in 64 % of all cases. This pattern was consistent for comparisons of species richness as well as overall measures of the presence of birds and insects (Colding and Folke, 2007). Petrosillo *et al.*'s (2019) literature study similarly suggests that golf courses may impact positively on biodiversity in urban contexts, although simultaneously having a harmful effect on water and soil aspects.

Tanner and Gange (2005) found greater bird and insect species richness and abundance, as well as a greater diversity of tree species, on golf courses in the United Kingdom, compared to neighbouring agricultural fields. In addition, Saarikivi *et al.* (2013) indicate that the well-maintained, artificial waterbodies on golf courses are ideal for providing amphibian breeding grounds, and housed as many spawning clumps as the surrounding natural reference sites. It therefore appears that golf courses, owing to their size and characteristics, have the potential to support biodiversity in the same way as other forms of UGI.

However, as mentioned in the previous section, golf courses are also known for their use of fertilizers and pesticides, non-native flora and human activity around the courses which suggest that these sites may negatively impact biodiversity (Guzmán and Fernández, 2014; Petrosillo *et al.,* 2019). Petrosillo *et al.* (2019) noted the decline in diversity (and ecosystem services) with the increased abundance of non-native floral species. They also indicate that wildlife, in particular, amphibians, would be negatively affected by the use of chemicals on golf courses, due to the contamination of water bodies (Petrosillo *et al.,* 2019). This is seen in Figure 1.1, where it is abundantly clear that water quality affects amphibian diversity. With these factors being highly prevalent in golf courses, the effect of golf courses on biodiversity appears to be complex.

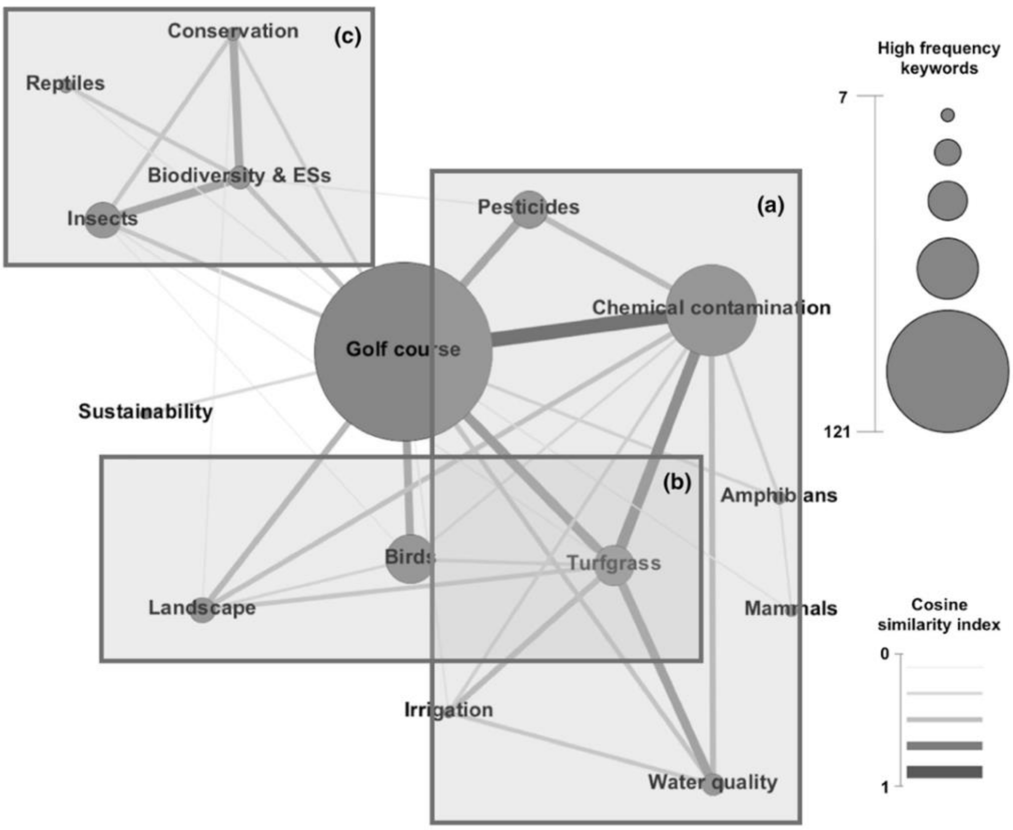

Figure 1.1: Co-word Network map indicating conceptual linkages between key words from studies addressing golf course's impacts and benefits, with (a) a cluster for chemical contamination, (b) bird conservation supported by golf courses, and (c) biodiversity/ecosystem services conservation (From: Petrosillo *et al.,* 2019).

1.3 Golf courses and connectivity

When considering the impact of golf courses on biodiversity, it is important to explore the connectivity of golf courses. It is widely accepted and recognised that connectivity is an important determinant of biodiversity of urban (and non-urban) green spaces (Bailey, 2007; Baguette and Van Dyck, 2007). Connectivity refers to the facilitation of species movement (Tischendord and Fahrig, 2000), and is used to aid and support biodiversity at different scales, and in different landscapes. Consequently, methods to enhance connectivity would need to be context-specific (Baguette and Van Dyck, 2007). For example, aquatic species rely strongly on structural connectivity (habitats physically touching or joined together) so that taxa such as fish can move from one area to another (Baguette and Van Dyck, 2007). The same applies to many species that would need to walk to move from space to space, especially in urban settings where buildings, roads and other grey infrastructure often separates green areas (Baguette and Van Dyck, 2007).

Bearing this in mind, connectivity does not always mean that patches of UGI need to be physically connected. For instance, birds and some insects are highly mobile species, and can fly from patch to patch, over or around intervening grey infrastructure, illustrating the importance of addressing both the structural connectivity of a landscape and the functional abilities and biological traits of species (Uezu *et al.,* 2005). Avian species require functional connectivity which demands consideration of the functioning of a landscape as a whole, whilst also addressing the species at hand and their characteristics allowing movement through and between patches (Uezu *et al.,* 2005). In addition, the movement of species between habitat patches is influenced and to an extent determined by the landscape in which the patches are situated (Tischendorf and Fahrig, 2000). Connectivity is thus made up of two components: structural, referring to the spatial configuration of habitat patches, and functional, or how the behaviour of a dispersing organism is affected by landscape structure (Baguette and Van Dyck, 2007).

Connectivity is not limited to the natural world and is also evident in the socioeconomic composition of urban settings, where both ecological and social connectivity may intersect. Within the urban landscape, connectivity can be seen and explored in three ways: people with people; people with nature; and nature with nature (Maciejewski *et al.,* 2021). Cities and urban areas are dynamic in terms of the flow of people; thus, attention to connectivity by city planners may facilitate or suppress this movement of people. For instance, urban areas typically include roads, railways and pedestrian walkways linking areas and allowing movement between people to take place (Maciejewski *et al.,* 2021). However, the structure and layout of cities and urban areas may also strategically limit the movement of people, as is evident in South African cities planned during apartheid, designed in such a way as to limit and restrict the moment of people, especially between various racially segregated areas (Lemon, 2021).

Urban areas do not only comprise social and social-technical systems, but also social-ecological ones (Frank *et al*., 2017). The integration of urban green spaces, the presence of natural energy flows, and even the hosting and supporting of urban adaptor species indicate the social and ecological connections (Maciejewski *et al.,* 2021). Urban adaptors, however, represent complexity within urban environments as many of these species' spread is facilitated by human alteration of habitat and therefore may represent species invasion rather than biodiversity richness. For example, the Hadeda ibis has been described as 'colonising' urban areas, as their expansion is facilitated by the urban environment in areas like the Western Cape in South Africa (Duckworth and Altwegg, 2014). Additionally, as seen with the facilitation of human moment through infrastructure networks, UGI also aids in this movement through its integration in the urban landscape in the form of greenbelts and corridors, easing movement of both wild species and humans (Frank *et al*., 2017).

Literature on eco-estates (many of which have golf courses linked to housing developments and conserved or rehabilitated natural landscapes) points to the significance of the connectivity of golf courses to other UGI, and the corresponding impact on biodiversity. A multi-taxa assessment of the three components of functional diversity, conducted by Alexander *et al.* (2019a) indicated that eco-estates in South Africa's KwaZulu-Natal province could mitigate the harms of populations expansion whilst maintaining ecosystem health. In another paper focused on the same context, eco-estates were connected to natural landscape as well as to one another, and were thus significant as patches with the potential to improve biodiversity and ecosystem functioning (Alexander *et al.*, 2019b).

Golf courses do not exist in isolation but rather form part of their neighbouring and surrounding landscapes, and so should be analysed from within this context. Despite various opposing views about the potential of golf courses to foster biodiversity, the context in which courses are situated is likely to play a prominent role in determining the levels of biodiversity which has not been extensively explored in the literature. The connectivity of golf courses to other UGI, or the lack thereof, may thus contribute to their potential to alter, enhance, or reduce biodiversity. These surrounding areas do not only alter biodiversity based on vegetation type but also change the landscape and its connectivity. Increasing connectivity and thus the size of green spaces (golf courses included) increases the biodiversity of an area (Bailey, 2007). Moreover, as noted by Adler and Jedicke, (2022); Morelli *et al.* (2018) with regards to avian species, it is not only the measures of connectivity that may be of importance, but also the scale at which they are measured as they refer to the importance of different scales. Thus, measures of connectivity at different scales is of utmost importance to include in any study addressing the biodiversity of specific, demarcated urban green spaces.

1.4 Golf courses, biodiversity, and connectivity

With the increasing need to conserve biodiversity, it is necessary to understand the functioning of systems and factors determining biodiversity as well as the actual levels of biodiversity to be conserved. Within an urban landscape, golf courses provide significant areas of green or semi-natural areas, of which many (parkland courses) have similarities to typical parks, which support an array of diversity. With contrasting views on golf courses' ability to promote biodiversity (Colding and Folke, 2009; Petrosillo *et al.,* 2019; Worster, 2008), further research is required to provide a more holistic picture of the environmental impact of golf courses, and the biodiversity they support.

In general, most studies of golf courses use birds as urban biodiversity indicators (Tanner and Gange, 2005). This is largely due to their sensitivity to change and ease of recording. However, some studies may use birds as indicators in conjunction with other indicator species, such as beetles, bees, insects, amphibians, reptiles and others (Colding and Folke, 2009; Tanner and Gange, 2005). Avian species are susceptible to change and thus are considered as good indicator species for environmental health and ecological change (Fraixedas *et al*., 2020) for several reasons: they have been monitored worldwide, are relatively easy to identify, are widespread and relatively diverse, have shown predictable population responses to ecological changes, and tend to be at or near the top of the food chain, meaning that they are sensitive to changes at lower trophic levels (Fraixedas *et al*., 2020). Many birds are also well-adapted to urban environments, with generalist species showing high levels of adaptability to change (Mekonen, 2017).

Meffert and Dziock (2013) find evidence pointing to the homogenisation of birds in urban environments. This poses a threat to their functional biodiversity (Kondratyeva *et al.,* 2020). Homogenisation in urban environments is the result of different species' adaption strategies, i.e., generalists and specialists, with generalists having the ability to live and thrive in a variety of habitats and use different food sources (Clavero *et al.,* 2011). Generalists therefore have the ability to better cope with change (Clavero *et al.,* 2011). This allows them to survive in areas of high pollution and disturbance in comparison to specialist species that are adapted to live within specific habitats and conditions and are thus less tolerant of to change (Clavero *et al.,* 2011).

When generalists increase in abundance in relation to specialists, negative implications for the environment and native species may occur, even though generalists also play significant roles in the urban landscape. One example of the positive role of generalists in the urban landscape is their contribution to the 'pigeon paradox', or the link between humans in the urban environment to that of the natural world (Reynolds *et al.,* 2021). Other examples are seen in how the House Sparrow (*Passer domesticus*) consumes food waste, how the California Quail (*Callipepla californica*) provides food opportunities for native species (humans included) as well as their dispersal of native fruiting plants (e.g., *Berberis buxifolia*) in Argentina (Codesido and Drozd, 2021).

Some studies use avian species to explore the impact of golf courses on biodiversity. For example, a study in Italy, using censuses of birds and predators on golf courses and surrounding urban-agricultural areas, investigated whether golf course can contribute to biodiversity in Italy. This study concluded that, in most cases, biodiversity was higher on golf courses than in surrounding areas (Sorace and Visentin, 2007).

Of the studies that do address biodiversity, most consider golf courses in relation to other natural, or semi-natural areas, such are old agricultural fields (Fox and Hock 2007; Sorace and Visentin, 2007; Tanner and Gange, 2005; Yasuda and Koike, 2006). There is therefore limited literature that considers golf courses in relation to urbanised contexts, where, as seen with parks and greenbelts, they form islands or pockets of biodiversity, areas that, unlike the urban surrounds, have elements to promote biodiversity. At the time of writing this study, two published studies (Saarikivi *et al.,* 2013; Wurth *et al,* 2020) include a comparison to urban areas in their studies of golf course biodiversity. Saarikivi *et al.* (2013) indicate greater numbers of amphibian spawning clumps in the most urban situated golf courses as compared to the more naturally situated ones. In contrast, Wurth *et al.* (2020), note that urban green spaces (golf courses included) as the least used space by coyotes, relative to agricultural lands and urban areas.

Despite the potential of urban golf courses to support biodiversity, the literature surrounding golf courses is limited in the Global South. In South Africa, few studies consider management strategies, and the perception of bird species (Mackay *et al.,* 2014; Jarrett and Shackleton, 2017). One study does compare the biodiversity of avian species between intact Strandveld vegetation and the remaining patches that are present within a neighbouring golf estate (Fox and Hockey, 2007). This paper, alongside others that consider the biodiversity of golf courses in other countries (Nooten *et al.,* 2018; Sorace and Visentin, 2007; Tanner and Gange, 2005; Yasuda and Koike, 2006), fails to include a measure of connectivity of the course under study and how this might influence biodiversity levels. Furthermore, there is limited mention of the factors determining biodiversity apart from the presence and size of the remaining Strandveld (Fox and Hockey, 2007). There do not appear to be any studies that compare the biodiversity of golf courses as UGI to surrounding urban areas, and that highlight the role connectivity plays in influencing the present diversity in the South African context.

From the literature, it appears that there is limited understanding of the effects of golf courses on biodiversity, especially within urban contexts in South Africa. Therefore, this study sought to address this gap in the South African context addressing both the potential to foster avifaunal diversity on Cape Town golf courses, as well as addressing the landscape context in which golf courses were situated. By doing so, a range of variables and factors that indicate diversity and connectivity were quantified. This project sought to assess the connectivity and landscape in which golf courses are situated, illustrating the importance of context and connectivity through an avifaunal diversity assessment of golf courses in South Africa. Four key questions guided this research objective: 1) To what extent are golf courses in Cape Town, Gqeberha and Johannesburg connected to other UGI? (outlined in chapter 3). 2) How and to what extent do golf courses affect the patterns and process of the greater urban landscapes of Cape Town, Gqeberha and Johannesburg? (outlined in chapter 3). 3) How does the connectivity of golf courses to other local UGI affect the avifaunal diversity of the golf course within Cape Town?

(outlined in chapter 4). 4) How and to what extent does the avifaunal diversity of golf courses differ from that of the surrounding urban landscape within Cape Town? (outlined in chapter 4). Lastly, 5) Is there any relationship between the extent and composition of vegetation and bird diversity within Cape Town's courses? (outlined in chapter 4).

1.5 Thesis structure

This chapter outlined the broad context and rationale for this study. The rest of this study addresses the gaps in the literature and research questions identified in this chapter. Chapter 2 outlines the study areas relevant for this dissertation. Chapter 3 explores the connectivity golf courses, and the way in which this connectivity may support biodiversity. It considers how the connectivity of golf courses measured in this study, spanning a range of South African cities relates to previous biodiversity studies of golf courses globally, and how the presence of golf courses affects the present connectivity, structure, and function of defined landscapes. Chapter 4 assesses the avifaunal diversity of Cape Town golf courses. Specifically, this chapter considers how and to what extent the avifaunal diversity of golf courses differs from that of the surrounding urban landscape, as well as the relationship between the extent and composition of vegetation and bird diversity. Finally, Chapter 5 provides the conclusion for this thesis. It synthesises key findings of this analysis, relating them to the literature. This chapter also serves as a reflection of the research overall, outlining the strengths and limitations of the study, and recommendations for future research in this field.

Chapter 2: Study area

2.1 South Africa overview

This thesis considers three South African cities, namely Cape Town, Gqeberha and Johannesburg (Figure 2.1), with an emphasis on the first, as Cape Town is the primary study site. Although the following chapters vary in terms of the number of cities they address, this section outlines and describes them all in order to give a comprehensive overview of the context of this study as a whole.

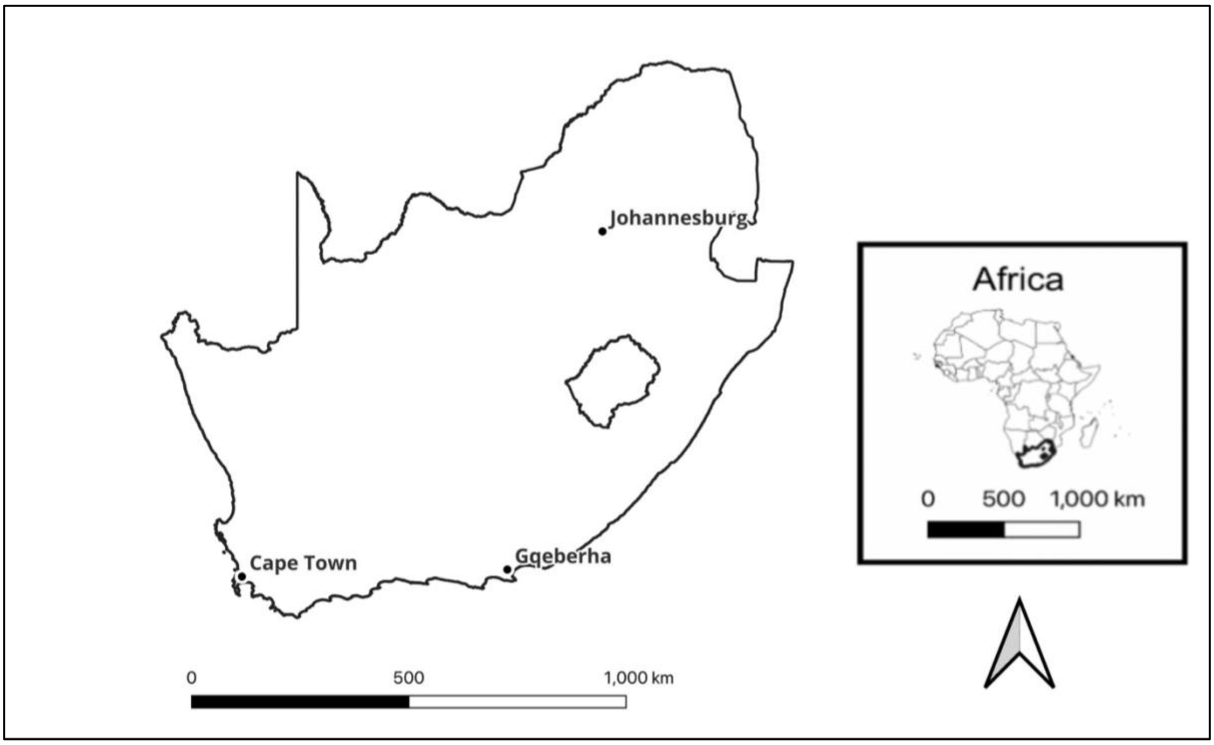

Figure 2.1: Map of South Africa showing the three study cities.

2.1.1 Demographic and socioeconomic characteristics

South Africa, situated in Sub-Saharan Africa, has a population of 62 million made up of 28.4 million women and 27.2 million men (Stats SA, 2022a). Black South Africans make up the vast majority, roughly 80.8 %. The second largest racial group, 'coloured' or mixed-race South Africans, make up 8.7 %, followed by white (7.6 %) and finally Indian/Asian South Africans (2.7 %) (Stats SA, 2022a). The country has extensive cultural and ethnic diversity, often referred to as the rainbow nation for this very reason. South Africa also faces the difficult historical legacy of apartheid. The apartheid regime entrenched racial and spatial segregation, and corresponding high levels of inequality (Davies, 1981). In the contemporary, ‘post-apartheid’ society, there remains a notable racial divide, clearly seen in the continued spatial segregation of cities (Stats SA, 2016a). Using Detroit, the United States’ most segregated city, as a benchmark, with a segregation index of 0.48, South Africa’s larger cities range from an index of 0.57 (Johannesburg) to 0.7 (Nelson Mandela Bay), where zero represents a fully integrated area and one corresponds to a completely segregated area (Stats SA, 2016a).

The present racial segregation in South Africa corresponds to high levels of poverty and inequality. Over 55 % of people are reported to be living in poverty (Stats SA, 2022b), with 64 % of the largest racial group (Black) living in poverty, followed by 41% of the ‘coloured’ population, six percent of Indians, and only one percent of white people, illustrating continued discrepancies in income along racial lines (Stats SA, 2022b). In addition, South African women are more impoverished than men, with 58 % of all women reported to be living in poverty, compared to 55 % of men (Stats SA, 2022b). Furthermore, present inequalities in South Africa are so great that South Africa, based on a Gini score of 63 (where a value of 0 represents absolute equality, and a value of 100 represents absolute inequality), is ranked as the most unequal country in the world that also has a GDP/per capita of 6 776.5 USD (World Bank, n.d a; World Bank, n.d b).

Nationally, 83.6 % of all dwellings are considered formal, 11.7 % are informal, and 4.2 % are traditional dwellings (Stats SA, 2021). Across the country, there is a low secondary school completion rate of 50.5 % and an even lower post-secondary completion rate of 14.6 % (Stats SA, 2021). In contrast, there is a relatively high adult functional literacy rate of 89.5 % (Stats SA, 2021).

The impacts and consequences of apartheid and colonialism are therefore still felt today, with strong evidence of racial segregation, disparities in wealth, education, and access to ecosystem services (Francis and Webster, 2019; Stats SA, 2016b). As seen in many places in the world, South Africa, and its cities, are subject to global warming along with many other challenges. As a developing country, described as having ‘normality with its informality’, South Africa faces many other issues, both environmentally and socially, with these feeding into each other (Myers, 2021).

2.1.2 South African flora and fauna

Paralleling its ethnic diversity, South Africa is a mega diverse country in terms of its fauna and flora. On a global scale, there are six floristic kingdoms, of which two geographically are found in South Africa (SANBI, n.d). Namely the Palaeotropical, and, of particular importance, the Cape floristic kingdoms. The Cape Floristic region is significant, not only for South Africa but the globe, due to its rich flora, housing more than 9 000 species of vascular plants (Goldblatt *et al.,* 2005) and species-level endemism of roughly 69 % (Linder, 2003).

There are nine terrestrial biomes in South Africa. These are the Albany Thicket, Desert, Forest, Fynbos, Grassland, Indian Ocean Coastal Belt, Nama-Karoo, Savanah and Succulent Karoo biomes (Rutherford *et al.*, 2006). These biomes are situated in different climatic, and geographic regions of South Africa. This is a consequence of its positioning between the Indian and Atlantic Oceans, and its high-altitude interior (Government Communications, 2016). Subtropical in location, with its above-mentioned geography, South Africa is relatively warm in temperature, with a mean annual temperature of 17.5 °C (Government Communications, 2016; World Bank, n.d c). It has dry conditions, receiving an average annual rainfall of about 464 mm (World Bank, n.d c).

2.1.3 South Africa in the context of this study

This study, which investigates the biodiversity of golf courses and their connectivity to UGI, explores the South African landscape in various ways. For this study, the connectivity of golf courses was addressed at a national scale, while biodiversity was addressed at a localised scale. Within the South African context outlined above, Cape Town, Johannesburg and Gqeberha were selected as the areas to explore more deeply. This is due to these areas as a whole, representing a wide range of urban and biophysical contexts outlined in sections 2.2.1, 2.2.2 and 2.2.3. With regard to the biodiversity aspect of this study, Cape Town was selected as the focal point due to its biodiversity as described in section 2.2.1, the fact that it has some of the longest established golf courses in the country, and because there is very little research about this in the Western Cape.

The three cities chosen for this study have a high proportion of vegetated cover compared to the global average. While Cape Town and Gqeberha are both coastal, they are very different in their climate and vegetation, as elaborated on in section 2.2 below. Johannesburg is located inland and on the plateau with many social differences from the other study sites. Considering the measured land cover of the cities, and the separation of blue/green cover from the grey cover (see Chapter 3), Gqeberha has the greatest proportion of vegetated cover, followed by Cape Town and then finally Johannesburg (0.85, 0.78 and 0.47 respectively) (Own data). The World Health Organisation's suggested minimum allocated area of public green space per person is 9 m^2 and an ideal amount is 50 m^2 (Morar, *et al.,* 2104; World Health Organisation, 2010). The three cities in this study (Cape Town, Gqeberha and Johannesburg) together, provided 449.25 m^2 (own calculations) of green space per person indicating a very high proportion of vegetated cover for urban areas. Using the SANLC data, the total area of green space was calculated, which was then converted to an area per person (SANLC, 2020). The main characteristic of each city touched on below are summarised in Table 2.1.

Table 2.1: Summary of the study sites.

Characteristic	**Cape Town**	**Gqeberha**	**Johannesburg**
Coastal/Inland	Coastal	Coastal	Inland
Latitude	33.55° S	33.96° S	26.20° S
Longitude	18.42° E	25.60° E	28.05° E
Biome (SANBI. n.d)	Fynbos	Thicket, Grassland, Nama-Karoo, Fynbos, Forest	Grassland
Climate (Climate to Travel, n.d a and b; CSIR, 2014)	Mediterranean	Subtropical oceanic climate	Subtropical climate
Average Altitude (m) (What is my elevation, n.d)	53	36	1 615
Population size (Stats SA, 2016b,c,d)	4 005 016	1 263 051	4 949 347
Population growth rate (%) (Stats SA, 2016b,c,d)	7.1	9.6	11.6
Mean annual rainfall (mm) (Climate to Travel, n.d a and b; CSIR, 2014)	515	625	700
Mean temperature (°C) (Climate to Travel, n.d a and b; CSIR, 2014)	17.6	18.1	16.65
Vegetated cover (%) (Own calculations)	78	85	47

2.2 Cities

2.2.1 Cape Town

Cape Town (33.9221° S, 18.4231° E) is located in the Western Cape province, the fourth most populated province in South Africa with a population of 4 million people (Stats SA, 2016b). Furthermore, the City of Cape Town municipality makes up two-thirds of the Western Cape population (four million residents) (Stats SA, 2016b). It has a population density of 1,530 persons/km^2, making it the second densest of the three cities explored in this study (Stats SA, 2011). It is structured around a mountainous peninsula, dominated by Table Mountain National Park. The city is one of very few globally to surround a national park. Table Mountain National Park (TMNP) hosts a vast array of indigenous fauna and flora, many of which are endemic. It is situated in the Cape Floristic region, further illustrating its significance concerning fauna and flora (Goldblatt *et al.,* 2005)

Being a coastal city surrounding a national park further makes Cape Town unique in terms of species present as well as in climate. Cape Town houses over 3 400 indigenous plant species, a number almost three times higher than some whole countries such as the United Kingdom which has only 1 200 indigenous species (Resource Cape Town, 2011a). Of those 3 400 species, 190 are considered endemic with 161 found in the Cape Peninsula (Resource Cape Town, 2011a). The rich and unique biodiversity is also evident in Cape Town's fauna. There are two endemic frog species found in the Table Mountain region (Resource Cape Town a, 2011). Apart from vertebrates, most of the endemic animal species are spiders and scorpions (31), followed by millipedes and centipedes (21), beetles (17) and then crustaceans (17) (Resource Cape Town, 2011a). This high level of endemism illustrates just how important Cape Town is as a biodiversity hotspot and underpins the need to conserve the natural areas of the city (du Toit *et al.,* 2021). Moreover, due to its coastal location, Cape Town affects marine species, both avian and aquatic.

In contrast to the rest of South Africa, Cape Town is characterised by a Mediterranean climate, experiencing winter rainfall and hot, dry summers. Temperatures range from an average monthly maximum of 22.8 °C in the summer (February) to an average monthly minimum of 10.8 °C in the winter (July and August) with a mean annual rainfall of 515 mm (CSIR, 2014). The warmest month, February, is also the driest, with an average rainfall of 16 mm, whilst June receives the most, with an average of 112 mm (CSIR, 2014). Of all provinces in South Africa, the Western Cape experiences the highest rainfall variation (CSIR, 2014).

The legacy of colonialism and apartheid provides insight into the level of poverty and inequality in the city. Cape Town (the Cape of Good Hope at the time) was originally occupied as a port and a stopover for traders by the Dutch East India Company in 1652, to the detriment of those already living on the land (du Toit *et al.*, 2021). The city is a former trading port established by the previous colonisers. This colonisation was not only the cause and reason for the placement and structure of many cities in South Africa and other previously colonised countries (Myers, 2021) but also resulted in the introduction of many non-native plant and animal species, deemed one of the greatest environmental impacts of the colonial regime (du Toit *et al.*, 2021). Cape Town is in many ways spatially and structurally determined by its colonial history and is made distinct by its physical geography and racial history. Notably, the structure of the city is infamously shaped by apartheid, a racial policy that segregated living areas by racial group, with Black people often pushed onto city outskirts (townships seen in modern-day South Africa) and rural areas (Smith, 2003).

Coupled with this overt legacy and present issue of segregation, the Cape (and South Africa at large) faces rapid, unpredictable, and informal urbanisation, with many people moving from rural areas to cities, hoping to find work, better education and health services, resulting in urban sprawl and densely concentrated townships (McConnachie and Shackleton, 2010; Mlambo, 2018). This rural-urban migration has accelerated since 1994 because previously it was restricted by the apartheid regime (Ramuhulu, 2021).

Rapid population growth overwhelms infrastructure, which partly explains the prevalence of urban sprawl and conditions of squalor, in turn exacerbating poverty and inequality (Godfrey and Julien, 2005). The informality of large sections of Cape Town is most evident in the Cape Flats, where a significant proportion of the city population resides (Resource Cape Town, 2011b). Furthermore, 18 % of the residents in the City of Cape Town live in informal housing and 29 % reside in government-subsidised dwellings with a total of 78 % of houses being considered formal (Stats SA, 2016b; Stats SA, 2011). The high urbanisation rate and urban sprawl in global south cities, as noted by Shackleton (2021), pose threats to critical biodiversity present in these expanding Global South cities (Anderson *et al.,* 2021).

Linguistically, Cape Town is diverse, with Afrikaans being the most spoken language (47 %), followed by IsiXhosa (31 %) and then English (20 %) (Stats SA, 2016b). The other eight official languages are also spoken, but each is spoken by less than one percent of the population (Stats SA, 2016b). Cape Town has a high Gini coefficient of 62 indicating huge wealth disparities (COGTA, 2020). Two million people or 46 % of Cape Town's population are deemed to be living in poverty based on the upper poverty line of R 1 227 per person per month (COGTA, 2020). This is due to the high level of unemployment (21 % in 2018) further explained by generally low levels of education (COGTA, 2020). Of the persons in the Western Cape that are 20 years and older, only 12 % have completed post-secondary education (Stats SA, 2016b).

Despite these challenges, Cape Town is one of the more affluent areas in South Africa. The Western Cape, in which Cape Town is located, has the highest household access to safe water compared to the rest of South Africa (Stats SA, 2016b). Cape Town has more than 5 000 ha of open spaces for the public (City of Cape Town, n.d). A large part of this 5 000 ha is open green spaces such as parks and greenbelts and excludes other forms of private or restricted green spaces (of which golf courses form part). Moreover, this number also excludes the 25 000 ha that makes up the Table Mountain National Park (SANParks, n.d).

Cape Town has 18 golf courses scattered throughout the urban matrix (Figure 2.2). The courses span both natural settings, as seen in the Atlantic Beach Golf Club neighbouring a nature reserve, and urban ones, as seen in the Royal Cape Golf Club course which is almost surrounded by residential and industrial zones. All 18 courses identified appear to be connected to other forms of UGI in one way or another, potentially benefitting from the green space by means of connectivity in Cape Town.

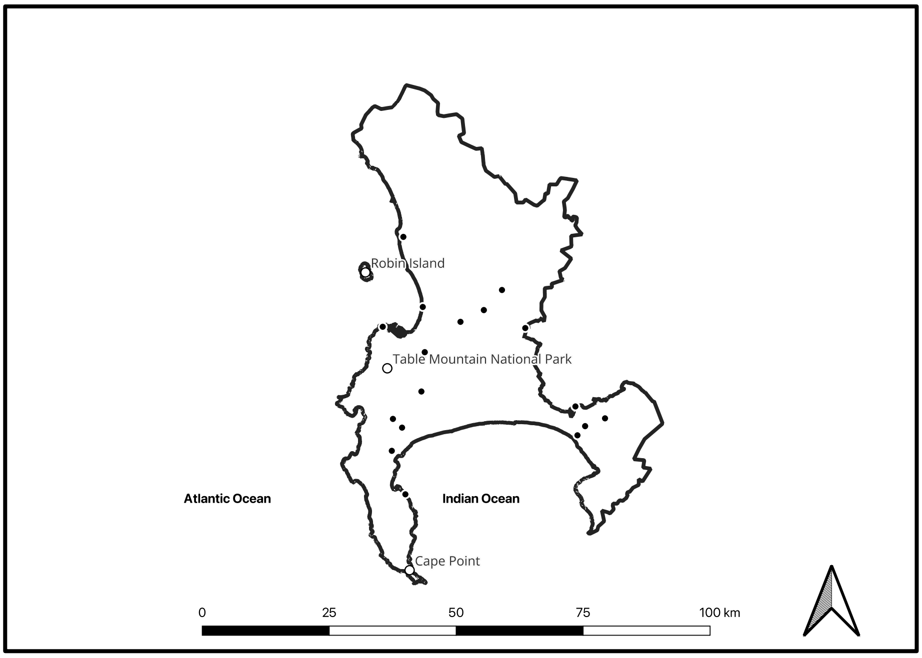

Figure 2.2: Distribution of golf courses within the bounds of the City of Cape Town municipality (Golf SA, n.d; Leading courses, n.d).

2.2.2 Gqeberha

Gqeberha (33.9608° S, 25.6022° E), formerly known as Port Elizabeth, is situated East of Cape Town, formed after the Cape of Good Hope when the British erected a military fort, Fort Frederick (Robson *et al.,* 2012) Gqeberha today is situated in the Eastern Cape province of

South Africa, a province with a total population of 6.5 million (Stats SA, 2011). Over one million people live in Gqeberha, making it the most populated area in the province with a population density of 588 persons/km^2 (Stats SA, 2011). The second most populated city in the Eastern Cape is Buffalo City (755 200) (Stats SA, 2011). Gqeberha is situated in the Nelson Mandela Bay Municipality, with the highest recorded segregation index (0.7) (Stats SA, 2016a).

Nelson Mandela Bay was established in 2001 as the administrative area incorporating Gqeberha, the surrounding towns of Uitenhage and Despatch, and surrounding agricultural areas (Stats SA, 2011). It is a major seaport and automobile manufacturing centre, forming part of the Coega Industrial Development Zone (IDZ), a multibillion-dollar industrial development complex, specifically for heavy, medium and light industries, one of the three major IDZs in South Africa (South African Marketing Insights, 2017; Stats SA, 2011).

Although there are some notable differences between the two cities, Nelson Mandela Bay shares some characteristics with Cape Town. Both cities were established by the Cape Colony, and are rich in their biodiversity (Nelson Mandela Bay Tourism, n.d; Resource Cape Town, 2011a; Robson *et al.,* 2012). It is located on the eastern extreme of the Cape Floral Kingdom, and its dominant biomes are fynbos and sub-tropical thicket (Nelson Mandela Bay Municipality, 2012). Gqeberha has five of nine South African biomes present, with the thicket most unique to the area (SANBI. n.d) (Table 2.1).Fauna is also well-represented, both on- and off-shore, and Gqerberha borders the Groendal Wilderness Area and Addo National Park, indicating proximity to landscapes focused on the conservation of biodiversity, especially elephants (Nelson Mandela Bay Municipality, 2012). Gqeberha has numerous nature and game reserves within and nearby the city. Additionally, Gqeberha's biodiversity is further promoted by the numerous biomes present (Table 2.1). Nelson Mandela Bay is culturally and linguistically diverse with, Xhosa, Afrikaans, and English being the most spoken languages (Nelson Mandela Bay Tourism, n.d).

The city experiences a subtropical oceanic climate, experiencing maximum rainfall in November (58 mm) and a minimum monthly rainfall of 39 mm (January) with temperatures reaching maximum monthly averages of 25.4 °C (January) and average lows of 10.1 °C (July) (Climate to Travel, n.d a). Gqeberha has a mean annual rainfall of 625 mm, ranging from 35 mm in the driest months (January and December) to 65 mm (2.6 in) in the wettest one (August) (Table 2.1) (Climate to Travel n.d a). In Nelson Mandela Bay, a 12 % higher education completion rate for residents corresponds to high levels of unemployment, sitting at approximately 36.6 % (Stats SA, 2011). Nelson Mandela Bay has the largest proportion of formal households out of the three studied cities, with a total of 92.4 % deemed as formal (Stats SA, 2016c).

2.2.3 Johannesburg

Johannesburg (26.2041° S, 28.0473° E) is South Africa's most populous city and forms part of the Gauteng province. Following the discovery of gold in the late 1880s, camps were set up, one of which was named Johannesburg (Latilla, 2018). Despite Johannesburg's abundance of greenery and vegetation, the area in which it is situated (Gauteng), is one of the smallest yet most populated areas in the country, with a population density of 2 696 persons/km^2 (Stats SA, 2011). The city is morphologically different to Cape Town and Gqeberha metropoles (Geyer *et al.*, 2015). Johannesburg and the Gauteng region have been described as a megalopolis due to vast urban sprawl and subsequent morphological changes, suggesting these differences in its urban densities (Geyer *et al.*, 2015).

Johannesburg's natural vegetation consists mainly of grasslands, which support an array of flora and fauna. From a biodiversity standpoint, however, the city is compromised, as a large proportion of these natural habitats have been transformed (City of Johannesburg, 2019). At the same time, Johannesburg's human-made urban forest is deemed one of the largest in the world, and the city houses approximately ten million trees, most of which are in private gardens, and could potentially support biodiversity (City of Johannesburg, 2019; Wende, 2010).

Johannesburg experiences a subtropical climate (Table 2.1). It has a mean of 700 mm annual rainfall making it the wettest of the three cities. Despite having moderate summers, with a monthly maximum average temperature being in January (24.4 °C), it also experiences the coldest temperatures compared to the other cities with its minimum monthly average (2 °C) in July (Climate to Travel, n.d b).

With five of the 11 official national languages (isiZulu, Sesotho, Setswana, English and Afrikaans) being widely spoken in Johannesburg, it makes it the most culturally diverse area out of the three areas chosen for this study (Stats SA, 2011). It has an unemployment and youth unemployment rate of 25 and 32 % respectively (Stats SA, 2011). In conjunction with the lower unemployment rate than that of Nelson Mandela Bay and Cape Town, there is also a corresponding greater higher education rate of 19 % (Stats SA, 2011). Johannesburg's formal households make up 81 %, slightly higher than the national average (Stats SA, 2011).

Chapter 3: Connectivity

3.1 Introduction

Urban biodiversity promotes ecosystem services and enhances human well-being (Fuller *et al.,* 2007; Jennings *et al.,* 2016; Shackleton, 2021). Therefore, it is necessary to conserve what is still intact. An emphasis on the conservation of biodiversity provides an opportunity to build sustainable, integrated and ecologically connected cities. In the Global South, cities are frequently characterised by informality and urban sprawl (Shackleton *et al.,* 2021). In such contexts, maintaining areas and habitats for biodiversity is challenging and increasingly warrants attention (du Toit *et al*., 2021). Urban sprawl may create opportunities for the incorporation of green spaces into the greater urban infrastructure as cities expand and 'engulf' peripheral green areas, absorbing them into the urban matrix. Often, however, urban sprawl is unplanned, which may increase the vulnerability of biodiversity (du Toit *et al.,* 2021; Anderson *et al.,* 2021).

Both planned and unplanned cities have a diversity of green areas, which provide different values and ecosystem services to people (Pauleit *et al.,*2021). Such spaces include parks, forests, riparian fringes, green belts, vacant lots and undeveloped lands, which have been widely studied (Pauleit *et al.,* 2021; Shackleton *et al.,* 2021). These urban green spaces provide services such as lowering of the urban heat island effect by parks and forests (Ngulani and Shackleton, 2020), aesthetic and recreational values (Palliwoda and Priess, 2021), and various provisioning services (Shackleton, 2021; Sitas *et al.,* 2021). These benefits are context-dependent, and perceived uses and users of these spaces are not static, shifting according to societal views and assigned values. In addition, differential access to urban green infrastructure (UGI) between high- and low-income areas remains prevalent, contributing to the 'luxury effect' or the generally positive relationship between affluence and biodiversity (Anderson *et al.,* 2021; Pauliet *et al.,* 2021).

Golf courses are especially large green spaces in urban areas, which makes them potentially important for a variety of urban ecosystem services and biodiversity if managed with these in mind. Some authors (Colding and Folke, 2009; Petrosillo *et al*., 2019) indicate that the placement of golf courses within an urban gradient may affect the diversity they contain. This illustrates that landscape context matters. However, the majority of literature assessing golf courses as UGI (Sorace and Visentin, 2007; Tanner and Gange, 2005; Yasuda and Koike, 2006) fails to conceptualise the role golf courses play in supporting biodiversity as part of a larger UGI matrix, as studies often consider golf courses in isolation from other UGI. Therefore, it is necessary to asses this, by considering how the connectivity of golf courses to other UGI may affect their biodiversity status, to better understand whether they function as green islands in the urban matrix, or are connected, influencing the levels of biodiversity they support.

Connectivity, or the facilitation of species movement between different spaces, in this case UGI, can increase biodiversity by enhancing the amount of UGI available for species to use, supporting more ecological functions and fostering to a more stable and resilient habitats (Bailey, 2007; Tischendorf and Fahrig, 2000). The extent to which connectivity is beneficial, however, depends on several factors, including the landscape in which patches are situated, and the extent to which species can move and disperse (Tischendorf and Fahrig, 2000).

Structural connectivity refers to the spatial configuration of habitat patches (Baguette and Van Dyck, 2007). Two patches may be structurally connected by an ecological corridor, enabling the movement of wildlife, connecting separated landscapes elements, and playing an important role in protecting biodiversity and in maintaining ecological functions (Zheng *et al*., 2019). Some species may be able to pass through ecological corridors, while others may not (depending on the characteristics of the corridor and species). For instance, a row of street trees as an ecological corridor may be too narrow or small for some species but may be beneficial to others, such as small, mobile mammals, avian species, and insects. For many avian species, many limiting factors would not apply due to their high mobility through flight provided the distance between separate patches is not too great.

With the current levels of urbanisation, fragmentation of natural vegetation and biodiversity occurs, disconnecting patches from one another and lowering resilience (Olds *et al.,* 2021). Thus, connectivity is a key aspect to address in the creation of sustainable cities and neighbourhoods. Connectivity is formed in many ways, one of which (in the urban context) is through urban forests and canopy cover (Mullaney *et al.,* 2015). In this sense, structural connectivity occurs in many forms, from street trees to riparian corridors and privately owned gardens that connect and link to each other.

It is not only the cumulative amount of green space within a landscape that aids connectivity, but also the size, shape and structure of UGI. Even patches that appear isolated or unconnected may house greater levels of biodiversity cumulatively at a landscape level, contributing to the functioning of the overarching landscape in which they are situated as they function together as 'stepping stones' (Bailey, 2007). An increase in patch size aids the facilitation of species movement whilst maintaining, or even enhancing, its functional abilities of supporting species (Bailey, 2007).

Furthermore, connectivity of a landscape is not only formed in a structural manner, but is also created in a functional sense, in terms of how the behaviour of an organism is affected by landscape structure (Baguette and Van Dyck, 2006). In this case, connectivity can be conceptualised as both the functioning of the landscape and the species at hand (Tischendorf and Fahrig, 2000). For instance, avian species, which are highly mobile, do not necessarily require a landscape with physically or structurally connected features, but rather patches close enough for species to fly between.

A few studies explicitly focus on connectivity of golf courses with some reference to biodiversity (Deslauriers *et al.,* 2018; Nguyen *et al*., 2020). However, the majority do not mention connectivity at all, or only as an afterthought (Sorace and Visentin, 2007; Tanner and Gange, 2005; Yasuda and Koike, 2006). Therefore, many studies that assess the biodiversity of golf courses in isolation from other UGI need to be reconceptualised to include connectivity considerations. Furthermore, some studies find a negative relationship between the presence of golf courses in natural settings and levels of biodiversity noted, but a positive relationship between golf course presence and biodiversity in urban or agrarian landscapes as observed in Petrosillo *et al*. (2019) work. This suggests that the landscape context is a crucial a consideration.

Golf courses are found in many different settings, such as urban, natural and agricultural, (Gange *et al.,* 2003; Sandberg *et al.,* 2016; Tanner and Gange, 2005). In addition, golf courses, excluding golf estates, are almost solely made up of vegetation or blue/green infrastructure and often much of their area is comprised of the rough or out of play areas which contain native and potentially ecologically valuable vegetation (Nguyen, 2022). Golf courses may play a role in reducing fragmentation by connecting patches together and thereby reducing edge length, and the vulnerability and fragmentation of an area (Bailey, 2007; Kleinn, 2011). This is broadly understood as the edge effect, whereby areas at the boundaries of two different habitats are more vulnerable to change, and therefore decreasing edge lengths may reduce this vulnerability and fragmentation (Kleinn, 2011). Given these characteristics, is important to assess how the connectivity of golf courses to other UGI may affect the level of biodiversity they are able to house and support.

In South Africa, most studies assessing golf courses focus on management practices, the post-apartheid shift and changes that followed, and perceptions of certain bird species (Cock, 2008; Mackay *et al.,* 2014; Manomano, 2013; Jarrett and Shackleton, 2017). There is limited literature examining the extent to which golf courses can support biodiversity. There is even less that considers the role of their interactions with the neighbouring landscapes and thus overlooks how connections to other UGI are likely to influence species richness and diversity.

Therefore, there is a need to consider the connectivity of urban golf courses to other UGI when assessing their levels of biodiversity. It is important to consider whether, and to what extent, golf courses are connected to the larger landscape in which they are situated, and how the connectivity of golf courses to other UGI may affect their biodiversity status. This study seeks to address this research lacuna. As golf courses are most often analysed in isolation from any connections to surrounding areas, especially in the South African context, this study aims to determine the level of structural connectivity of urban golf courses in several South Africa cities, and then assess how and to what extent golf courses affect the patterns and process of the greater urban landscape. Key research questions relating to this chapter include: 1) How, and to what extent, are golf courses in South Africa connected to other UGI? 2) What is the difference in structural connectivity of golf courses across different South African cities (see section 3.2.1)? And 3) How does the presence of a golf course affect the connectivity, structure, and function of the broader urban landscape?

To answer these questions, various metrics were selected and analysied. Metrics such as land cover and landscape proportion were selected as they measure the exact amount of vegetated space present, indicating and describing whether landscapes are more vegetated or urban. With an increase in these measures, there is a corresponding increase in structural integrity of the landscape at hand (Fahrig, 2003). Given literature that addresses distance between patches or areas of blue/green infrastructure, Bailey (2007) notes the importance of the number of woodlands within 0.5 km from their focal point (or here, a golf course) as an important influence on the extinction and colonisation rates of avian species.

Two other metrics significant for this study were mean patch area and greatest patch area. These metrics help describe landscape aspects and functional traits of natural space, and indicate changes or difference in patch size, which have implications for habitat and biodiversity loss (Bailey, 2007). These metrics describe fragmentation of a landscape; where across a range of different patch sizes, as these increase, so too does connectivity, whilst fragmentation decreases (Gökyer, 2013). The number of patches also helps describe the patterns and process within the landscape, aiding an analysis of functional connectivity (Bailey, 2007).

Edge length was also a chosen metric as it gives insight in the impact golf courses have on the edge effect within urban landscapes. Edge length is better understood in conjunction with other metrics, namely number of patches and land cover. For example, the interconnectedness of these metrics is illustrated by the fact that the sensitivity of a habitat increases when land cover remains constant, yet edge length increases, creating a more sensitive edge area and a lowered stable interior as the interior becomes closer to the edge (Fonseca, 2008). The same is true for the number of patches. Furthermore, according to Kleinn (2011) an increase in edge length is closely linked to higher fragmentation in a landscape. The following methods and materials section clarifies the scales and landscape metrics used in more detail.

3.2 Methods and materials

3.2.1 *Mapping*

Golf courses were mapped following the identification of all golf courses in three cities, namely Johannesburg, Gqeberha and Cape Town. Golf courses were identified using various online platforms, whereby the search parameters were limited to the boundaries of the three cities (Golf SA, n.d; Leading courses, n.d). The perimeter of each golf course was mapped and their boundaries were traced using overlayed satellite imagery (Google Earth Pro, 2023). This mapping was performed using Quantum GIS (QGIS) version 3.22.0, an open-source geographical information system (GIS) programme (Figure 3.1) (QGIS, 2022).

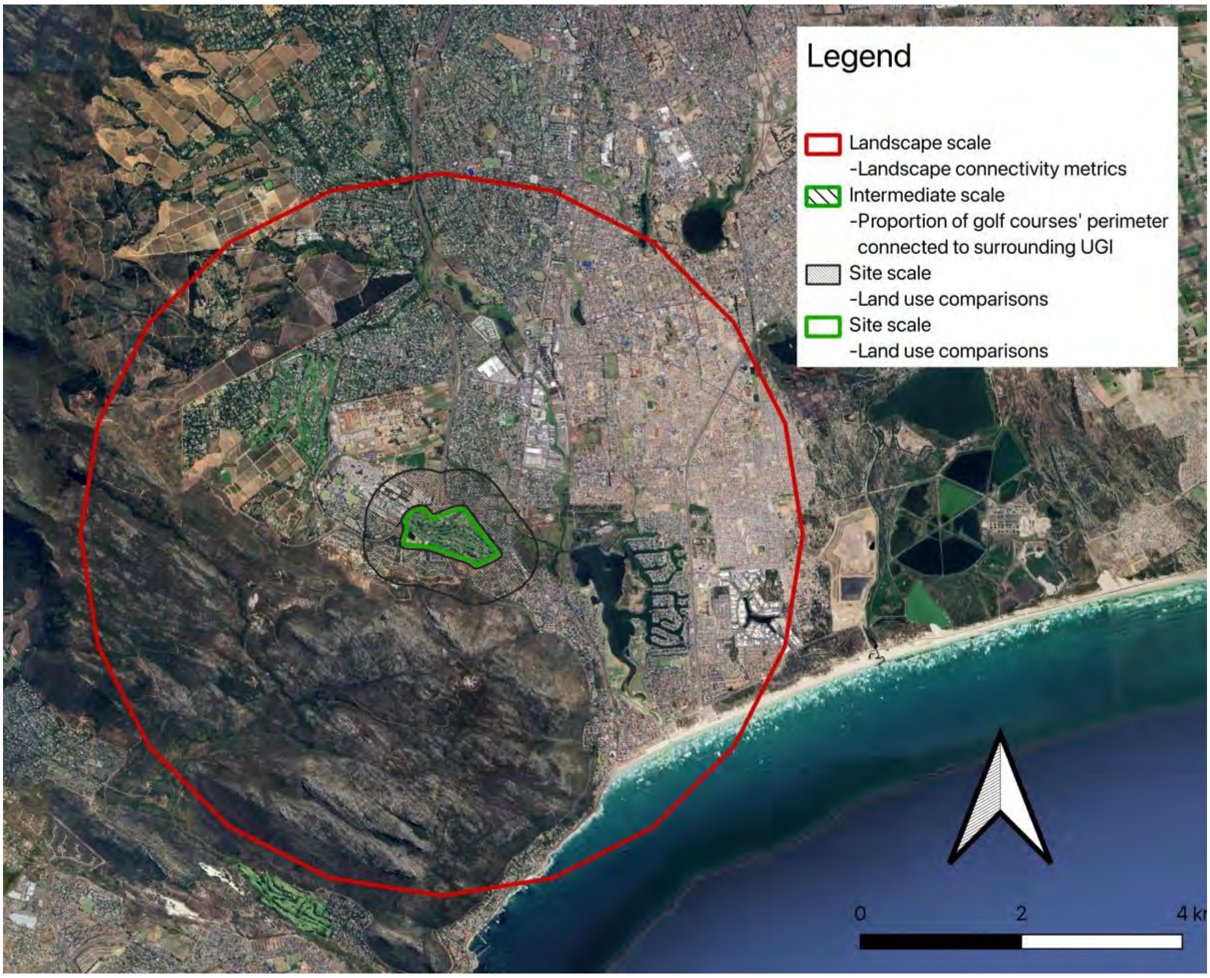

Figure 3.1: The designation of the different scales at which specific metrics were analysed.

For the investigation of the extent to which golf courses are connected to other UGI, as well as their contribution to the overall landscape connectivity and functioning, a broader landscape was first identified, the landscape scale (Figure 3.1). An area of 6 224 ha (4 489 radial meters) was selected as the bounds to this landscape (Figure 3.1), centred around a median coordinate of each golf course. This size was based on the average home range of a selection of avian species in urban areas specifically (O'Donnell and del Barco-Trillo, 2020). Due to the limited literature on urban home ranges of birds and the apparent difference between urban and natural home ranges, O'Donnell and del Barco-Trillo's (2020), meta-analysis was used as a base line for this calculation. This approach did have some limitations as the meta-analysis focused primarily on Northern birds. Where this meta-analysis referred to the same species multiple times, the average home range for each species was calculated. All home ranges (area units) were first standardize prior to averaging them out.

This defined landscape scale allowed for connectivity of avifauna to be assessed in these urban areas. It also assisted in linking the findings in this study to those in Chapter 4, which focuses specifically on avifaunal diversity of selected golf courses. Additionally, avifauna are said to respond differently to variables at different scale, where the landscape and habitat (site specific) scales have been stressed Adler and Jedicke, 2022; Morelli *et al.,* 2018). This was the measure of the golf courses boundary. In addition to the landscape scale, an intermediate scale was demarcated, that both incorporates the golf courses and the directly surrounding areas (everything within 0.5 km of the golf course's perimeter) (which includes part of the site scale). The boundaries of this scale were that of the 0.5 km buffer constructed around the golf course perimeter. The 0.5 km buffer represents the areas directly surrounding golf courses and is drawn from Tanner and Gange's (2005) work, which indicated that this 0.5km buffer describes directly neighbouring areas (in the case of their study, the authors wanted to exclude directly surrounding areas, and did not analyse this buffer – whereas this study only seeks to consider these directly surrounding areas). Using the same buffer distance also means that direct comparisons can be made. (Figure 3.1).

In addition to the two scales for structural connectivity analysis, a site scale was also outlined in Figure 3.1, which is similar to that of the intermediate scale as it incorporated both the golf course and urban surrounds, however addresses them separately (Figure 3.1). Finally, for the description of the three cities used in this study, a city scale was also used encompassing the entirety of the cities. The administrative boundaries to the city were used to determine this scale (Esri, 2023).

3.2.2 *Land cover classification*

Connectivity analysis took place in QGIS, making use of the South African National Land Cover Map (2020) (SANLC, 2020) as a means of assessing what landscapes golf courses were connected to and to what extent. The Landscape Ecology Statistics (LecoS) plugin (Conservation Ecology, n.d; Jung, 2022.) was used to assess landscape connectivity metrics at the landscape scale. The LecoS plugin converts raster and vector data into metrics, and these metrics were quantified allowing for statistical analyses to follow.

To calculate connectivity metrics, a reclassified version of the South African National Land Cover Map (2020) (SANLC, 2020) was overlayed at the landscape, intermediate, site (figure 3.1) and city scales. The SANLC comprises of 73 different land classes which were re-classed into seven classes (Table 1 in Appendix) to allow for easier analysis of golf courses' relationship to the intermediate connectivity and to compare the land uses between the golf courses (site scale). These seven classes were: Agriculture; Bare or Bare ground; Residential vegetation (including lawns and recreational grasses); Urban or Grey Infrastructure; Natural vegetation; Water and Other.

For the connectivity analysis at the landscape scale, the seven groups were further reclassified further into two classes, a blue/green (or vegetated) class and a grey (urban) class (Table 2 in Appendix). The classification scheme grouped together all aquatic and vegetated (blue/green) areas except for residential lawns, as well as all non-natural areas (grey) as a second class. The SANLC map made use of 20 m × 20 m pixels to describe underlying land cover, resulting in some substantial overlapping of land uses at a fine scale as seen in Figure 3.2. This was the reason for the exclusion of residential lawns from the re-classed natural class. Residential lawns, when classified as 'green' or 'natural', ended up representing a high proportion of urban/residential areas as there was substantial overlap between the two land uses. There was also an overlap with urban/residential areas and natural/green areas when residential lawns were removed from the green category. For the latter, the proportion of overlap was lower and therefore deemed more accurate to have residential vegetation areas excluded from the green/natural category (Figure 3.2). With the presence of green infrastructure inequitably distributed in Global South cities between high- and low-income areas (Venter *et al.,* 2020), the representation of grey infrastructure as residential lawns as per the SANLC map due to its coarse resolutions was tested in both high and low income areas (Figure 3.2).

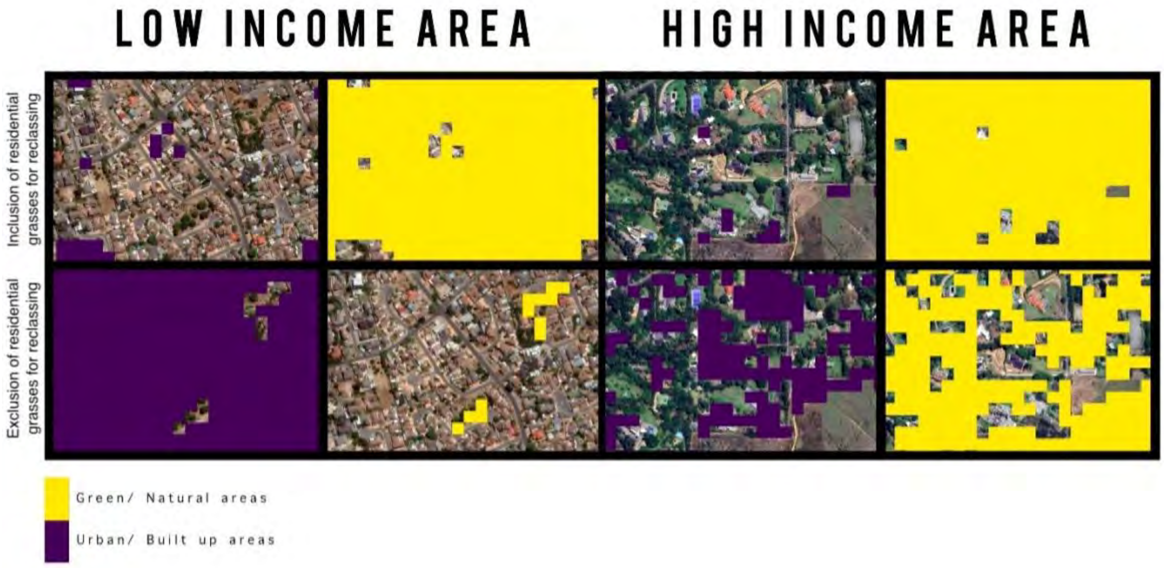

Figure 3.2: Illustration of how the inclusion of residential grass skews the visual and subsequent ecological metrics of the present land cover base on two study sites in Cape Town spanning both high- and low-income areas.

The above was repeated to create a 'reference landscape', one free of golf courses. This was done by excluding the 'urban recreational field tree' (class 61), 'urban recreational field bush' (class 62), and 'urban recreational field grass' (class 63) classes from the blue/green class to create this golf course 'free' landscape (Table 2 in Appendix).

The reclassification of land classes into a blue/green and a separate grey class was performed using the GRASS 'reclass' tool on QGIS, creating two different maps at the larger landscape scale for each golf course (Figure 3.3). One map included golf courses whilst the second map excluded golf courses. Golf courses were represented by certain land classes, of which these were either included or excluded in the reclassification process as to create the 'golf course' and 'reference' landscapes (at the landscape scale). The included and excluded classes can be seen in Table 2 in Appendix where 1 = included classes in the re-classed natural class, and 0 = the excluded classes.

Figure 3.3: Landscape scale with and without the golf course Raster data present.

3.2.3 *Structural connectivity at the intermediate scale*

Following the land cover classification process, the physical connectedness of golf courses to surrounding UGI in the three cities were measured. Initially, the perimeter for each course was calculated (in meters). Following this, the cumulative perimeter of each of the seven land cover groups (reclassified from the SANLC classes) surrounding and touching each of the golf courses were measured as a proportion of the entire golf course perimeter along with the proportion of only the blue/green infrastructure (from the two groups generated).

These proportions served to indicate whether the golf courses analysed exist in isolation from other natural and semi-natural areas making them 'islands' or a patch, or if they were physically connected to the surrounding landscape. In addition, the individual proportions (the seven different groups) provided insight into the type or quality of connectivity between golf courses and other UGI in the vicinity.

3.2.4 *Landscape connectivity at the landscape scale*

Following this classification process and structural connectivity analysis, landscape factors that influence connectivity were analysed. Landscape metrics were used to assess landscape factors and processes that describe and influence connectivity. Landscape connectivity was assessed using six metrics: land cover, landscape proportion, edge length, number of patches, mean patch area and greatest patch area. These metrics, along with the land uses, were selected based on their ability to describe a wide range of connectivity aspects whilst addressing both functional and structural connectivity (Keeley *et al.,* 2021) (Table 3.1).

Table 3.1: Summary of metrics chosen for connectivity analysis.

Metric	**Definition**	**Use**	**Reference**
Land Cover	The total cumulative area of the defined green spaces (both natural and non-natural spaces).	Describes the landscape land uses, indicating a more or less vegetated, connected and/or stable landscape.	Bailey, 2007
Landscape proportion	The proportion of the total defined landscape that consists of green spaces (both natural and non-natural).	Shows how natural/green the landscape is in relation to the remainder anthropogenic uses/areas present in the landscape.	Bailey, 2007
Edge length	The cumulative length of the perimeters of all the green spaces or patches.	Edge length and the edge effect not only show or indicate the sensitivity of a landscape or the patches in it, but also indicate how fragmented the landscape is.	Bailey, 2007; Kleinn, 2011
Number of patches	The total number of all separated/non-touching green spaces (each area is a patch).	Indicates how intact or fragmented the landscape is, suggesting higher or lower sensitivity and connectivity of the landscape.	Bailey, 2007
Mean patch area	The average area of the patches.	Gives insight into the stability or sensitivity of the present patches as well as their ability to aid and support biodiversity.	Bailey, 2007
Greatest patch area	The area of the largest patch or green space	Can indicate habitat and biodiversity gain/loss as well as increases or decreases in fragmentation and connectivity.	Bailey, 2007

These metrics were calculated for both the 'golf course' and 'reference' landscapes (at the landscape scale) using the Landscape Ecology Statistics (LecoS) plugin on QGIS. The results were then exported from QGIS to Excel and then finally to RSstudio for data analysis. For landscape proportion and number of patches, the units were converted into proportion per ha to account for the removal of the golf course raster data from the same landscape (Equation

3.1, 3.2 and 3.3). Land cover was also adjusted to accounted for the removal of the golf course to create the reference landscape. This was all performed at the landscape scale.

$$\text{new area} = 6\,224 \text{ ha (landscape scale size)} - \text{golf course and recreational area} \ldots \text{EQ.3.1}$$

Equation 3.1: Calculating the new areas of the landscape without the golf course being present.

$$\text{patches per ha} = \text{number of patches} / \text{new area} \ldots \text{EQ.3.2}$$

Equation 3.2: Calculating the number of patches per ha.

$$\text{landscape proportion} = \text{land cover} / \text{new area} \ldots \text{EQ.3.3}$$

Equation 3.3: Calculating the land cover proportion.

3.2.5 *Data analysis using landscape metrics*

The data obtained on QGIS addressing the structural connectivity of the golf courses at the intermediate scale were analysed within each city, but also between the cities. Within each city, the proportions of connected UGI (blue/green infrastructure) were calculated, along with the average, maximum, minimum and standard deviations. This was repeated for each of the seven land uses to allow for statistical testing between each city in the form of Kruskal-Wallis test, where the null-hypothesis assumed no difference between the cities. This was followed by a post-hoc test to address any significant parings in the means between any two cities. The Dunn's post-hoc test was adopted. All data underwent normality testing to determine if a parametric or no-parametric test was most appropriate as well as tests for heterogeneity or variance. All statistical analyses were performed on R studio, version 2022.02.3 (R Core Team, 2021). The landscape connectivity data obtained at the landscape scale were then assessed in relation to the level of connectivity of each course at the intermediate scale. This took the form of multiple linear regressions where the connectivity at the intermediate scale was the dependent variable whilst the landscape scale metrics were used to describe the change in connectivity. The cities were fixed variables.

The landscape scale connectivity metrics obtained via the LecoS Landscape Ecology tool were divided into two groups, with one group containing the golf course data in the landscape and one with the course removed. With the area of the landscape uniform across all the courses, the removal or subtraction of differently sized golf course areas from these areas resulted in many, differently sized landscapes. This called for the reporting of the metrics and their units as proportions rather than as nominal units. Totals, averages, standard deviations, maximum and minimum units for the two different landscape types were calculated. The same was done for each city. These two groups were created for each of the landscape metrics (landscape proportion per ha, edge length, mean patch area and greatest patch area), where they were tested for significant differences using the nonparametric Wilcoxon Rank Sum Test.

3.3 Results

Across the three cities, there were 51 golf courses with a cumulative area of 3 551.5 ha, and an average of 69.6 ha (± 34.7 ha). Additionally, the average perimeter of the golf courses was 4 851.5 m (± 2 167.7 m), with the largest being to Dainfern Golf Course (1 3501.6 m) (Johannesburg) and the smallest perimeter to Simonstown (Cape Town) (1 557.0 m) (Cape Town). Every golf course was connected to other UGI to some extent. On average, surrounding UGI made up 58.9 % (± 22.2 %) of the golf course perimeter, suggesting a high level of connectivity (Table 3.2), ranging from 3 to 100 % for Simonstown golf course (Cape Town) and Kyalami (Johannesburg) respectively, indicating that they do not exist in isolation or as islands, but rather are structurally part of the UGI present. Golf courses were predominantly green on average (site scale), with residential vegetation making up the greatest proportion of area (88.1 ± 13.8 %). This was followed by natural vegetation contributing 7.2 % (± 11.3 %).

Table 3.2: The percentage of golf courses' perimeter connected to other types of UGI and urban infrastructure across the three cities at the intermediate scale.

Land use class	**Cape Town**	**Gqeberha**	**Johannesburg**	**Total**
Agriculture	5.6 ± 11.5	0.0 ± 0.0	1.3 ± 6.7	2.6 ± 8.4
Bare	2.4 ± 7.2	0.8 ± 1.3	2.3 ± 5.7	2.1 ± 5.8
Residential vegetation	24.9 ± 24.5	49.1 ± 18.2	43.2 ± 21.1	37.6 ± 23.7
Natural vegetation	15.0 ± 22.7	20.6 ± 16.8	15.6 ± 17.2	16.2 ± 18.9
Water	4.0 ± 12.3	0.0 ± 0.0	2.1 ± 4.9	2.5 ± 8.0
Total UGI	49.4 ± 25.2	69.7 ± 18.4	62.2 ± 19.1	58.9 ± 22.2
Urban	48.1 ± 23.0	29.7 ± 19.1	34.1 ± 18.8	38.4 ± 21.3
Other	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 7.0	0.7 ± 4.9

On average, grey infrastructure made up the largest proportion of connection to golf courses (38.4 %) (Table 3.2). This was followed by residential vegetation (37.6 %) and then natural vegetation (16 %). Agriculture, water, and bare ground contributed on average similar amounts (2.6 %, 2.5 % and 2.1 % respectively). The 'other' class, made up less than 1 % (0.7 %). These results further correspond to the proportion (area) of land cover surrounding the courses, where grey infrastructure was the largest (0.38 ± 0.21) followed by residential (0.38 ± 0.24).

Cape Town was the largest city covering of 2 240.6 km^2, followed by Gqeberha (1 957 km^2) and finally Johannesburg with an area of 1 642.6 km^2 (Esri, 2023). The area of UGI was substantially different between the three cities, being highest in Cape Town and Gqeberha compared to Johannesburg. Cape Town and Gqeberha had 1 741.7 km^2 and 1 667.1 km^2 of green infrastructure, respectively, compared to 781.3 km^2 in Johannesburg (Table 3.3). The proportion of the total landscape followed in the same order as seen in Table 3.3. In addition, differences were further noted for the presence and abundance of all the regrouped land uses within and between the cities at the golf course landscape (Figure 3.4). There was however limited difference in the presence of residential vegetation between and within the cities, except for Gqeberha, where large deviations are noted (Figure 3.4).

Table 3.3: The area and natural vegetation cover in Cape Town, Gqeberha and Johannesburg.

Area and vegetation measures	**Cape Town**	**Gqeberha**	**Johannesburg**
Area of city (km^2)	2 240.6	1 957.0	1 642.6
Area of natural vegetation within the city (km^2)	1 741.7	1 667.1	781.3
Proportion of vegetated cover within the city	0.8	0.9	0.5
Vegetated area per person within the city (m^2)	469.7	1 446.9	176.2
Vegetated area within the landscapes scale (km^2)	35.2 (± 15.1)	4 0.9 (± 1 1.8)	2 7.5 (± 6.7)
Proportion of natural vegetation on golf courses	0.3 (± 0.3)	0.2 (± 0.2)	0.2 (± 0.2)
Proportion of residential vegetation on golf courses	0.3 (± 0.3)	0.5 (± 0.2)	0.4 (± 0.2)

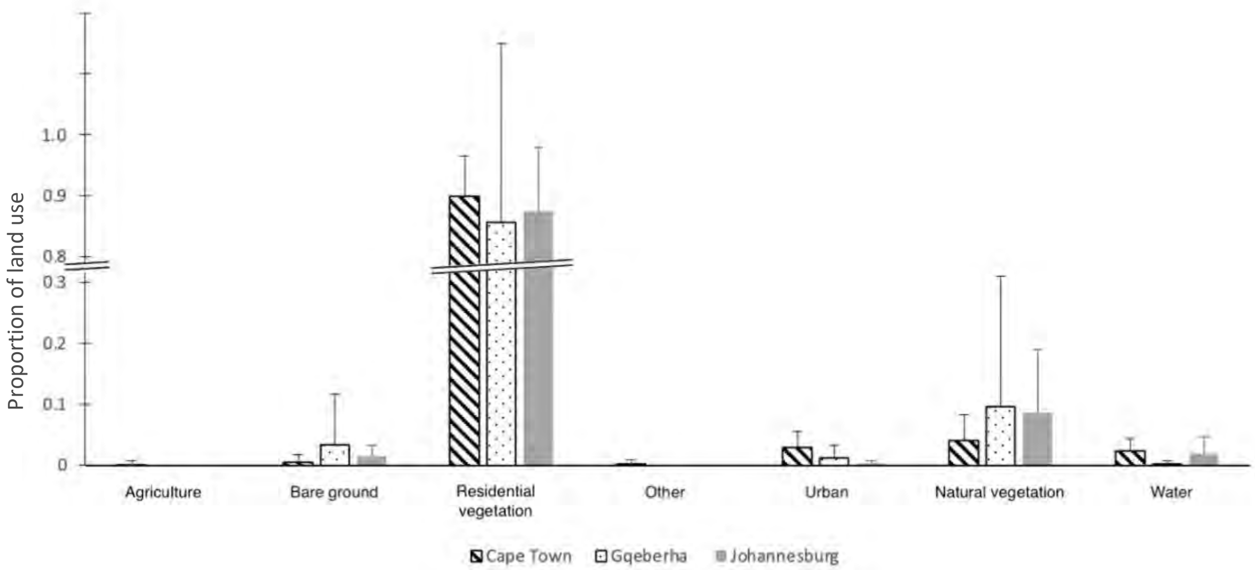

Figure 3.4: Differences in land uses present within and between Cape Town, Gqeberha and Johannesburg.

Of the 51 golf courses, 18 were situated in Cape Town, eight in Gqeberha, and 25 in Johannesburg. The largest golf course was in Johannesburg, namely the Country Club Johannesburg, with an area of 209 ha, whilst the smallest golf course, found in Cape Town, (Simonstown Country Club) which had an area of only 10.2 ha. On average, Gqeberha's golf courses were situated in more natural landscapes, where the average green infrastructure cover within the predetermined 6 224 ha 'landscape scale' was 4 091 (± 1 183) ha, compared to Cape Town and Johannesburg where the average natural land cover was 3 517 (± 1 513) ha and 2 754 (± 669) ha, respectively (Table 3.3). This however did not correspond to the extent to which golf courses were connected to the intermediate landscape. Gqeberha's golf courses were most connected to the intermediate landscape (0.70) as well with the highest levels of vegetation cover (both at the city and landscape scale). After Gqeberha, Johannesburg golf courses appeared most connected to the intermediate landscape (0.62), although the city exhibited the lowest levels of vegetation at the city scale and golf course landscapes scale (see section 3.2.3). Cape Town golf courses, despite being situated in the city with the second highest cover of vegetation at both the city scale and landscape scale, appeared least connected to the intermediate landscape (0.49).

Whilst the range in the level of connectivity was substantial, ranging from 0.49 for Cape Town to 0.70 for Gqeberha the one-way Kruskal-Wallis indicated that there was no significant difference between the three cities ($p = 0.1$) when addressing all UGI together. Furthermore, the post-hoc test indicated no relationships between any of the cities. This held for the additional grouped land uses with the exception of 'residential vegetation' indicating significant differences ($p = 0.037$ and $p = 0.034$). Finally, the post-hoc test for residential vegetation illustrated that Cape Town was different to Gqeberha and Johannesburg (who were grouped together).

Further significant differences between the cities were noted in all the measured landscape metrics (except mean patch area) (Figure 3.5). It was noted that Gqeberha has the most intact and connected landscape as it on average had the greatest land cover (40.90 km^2) and patch area (32.27 km^2), whilst also have the fewest number of patches (1 130.50) and the second shortest edge length (570.66 km). This contrasts with Johannesburg, having the lowest land cover (27.54 km^2), the smallest largest patch area (17.28 km^2) whilst also having the most patches (1 564.52) and greatest edge length (1 098.72 km).

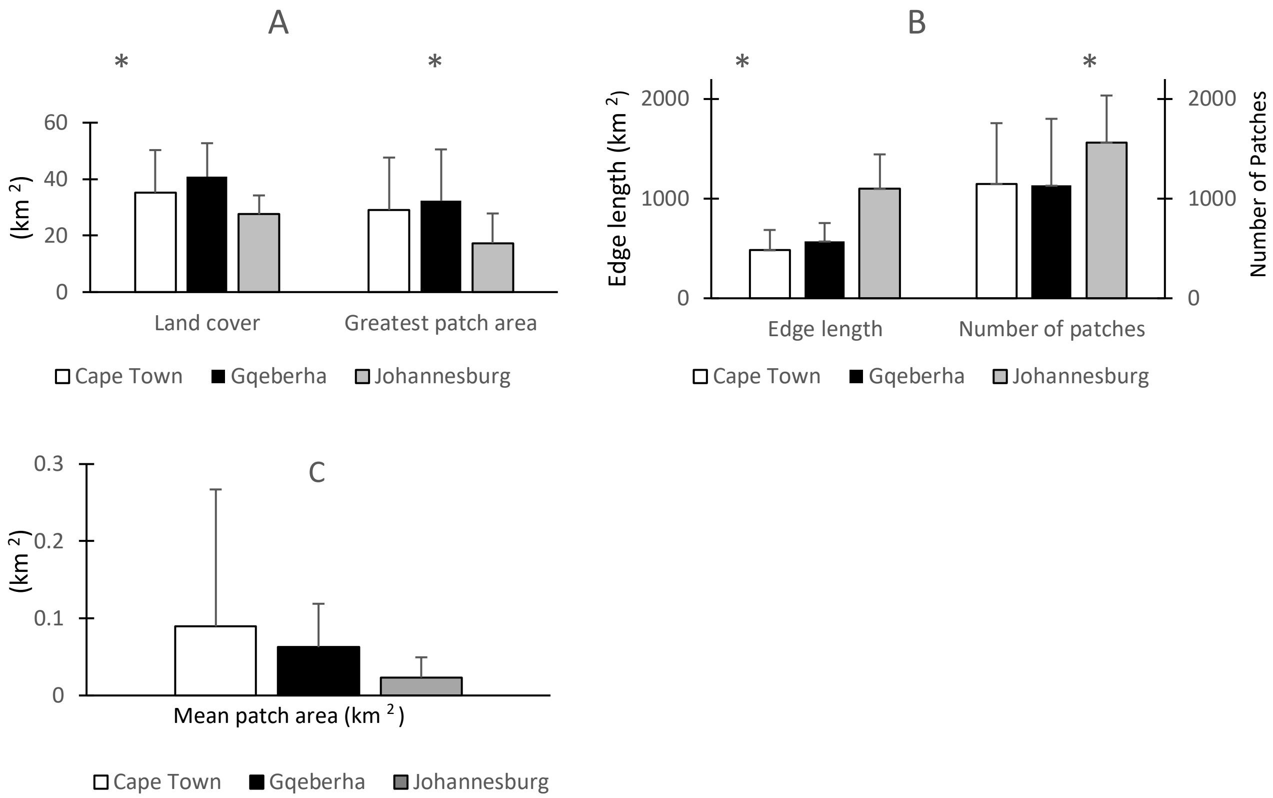

Figure 3.5: Measured landscape metrics between the three cities.
(Signif.codes: <0.05‘*’)

Large and significant differences in landscape structure and function between the three cities were evident (Figure 3.5). A linear regression addressed these landscape metrics in relation to the extent to which golf courses were connected to the overall landscape (situated in the analysed landscapes) indicated no relationships (Figure 3.6).

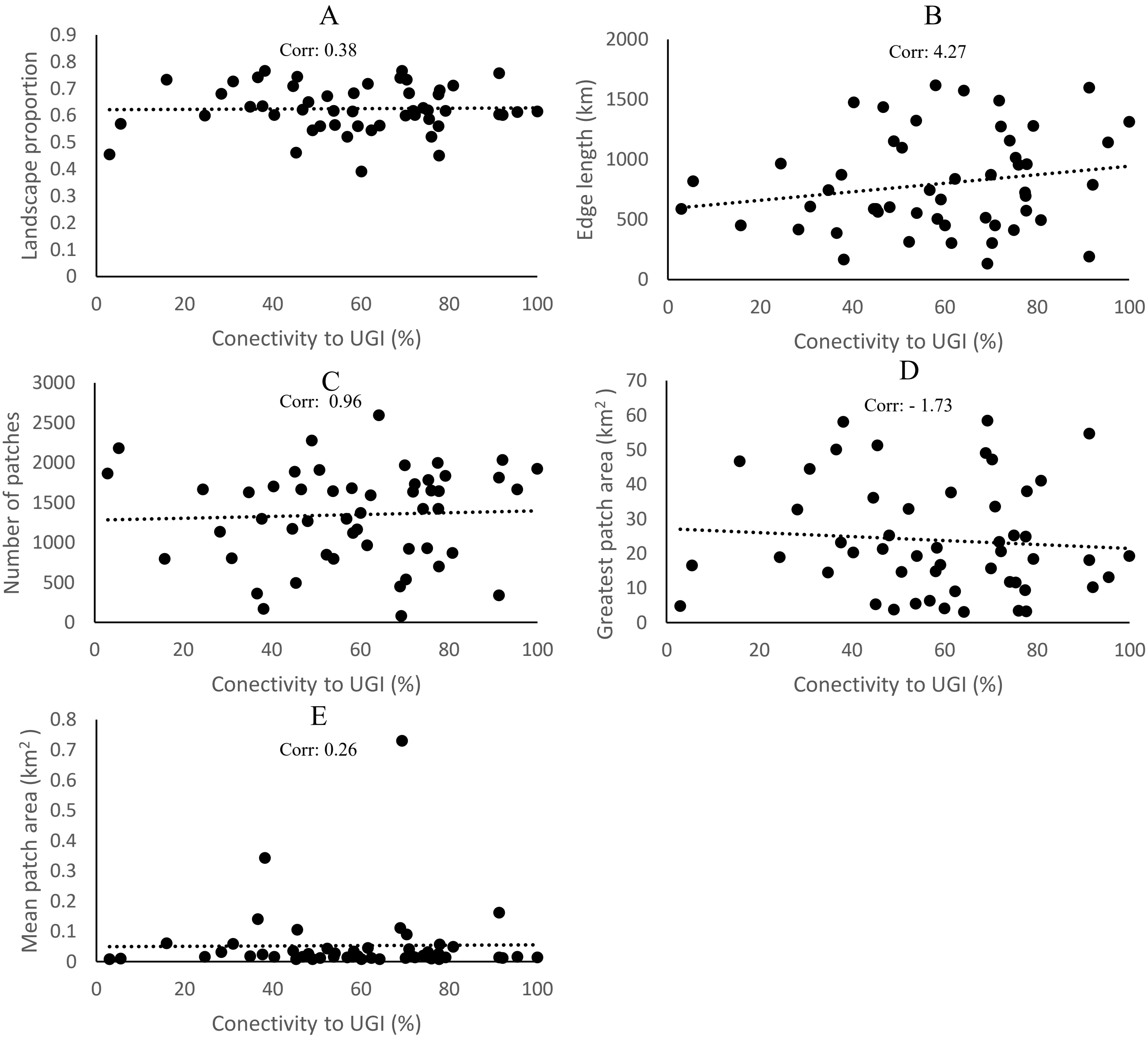

Figure 3.6: Individual linear regressions of various landscape metrics (Dependent variables) (A) Landscape proportion, B) Edge length, C) Number of patches, D) Greatest patch area, and E) Mean patch area) and the extent to which golf courses were connected to other forms of UGI (Independent variable). n = 51.

Due to the typically large size of golf courses, there is the potential that they could enhance the level of UGI connectivity in cities. This was not the case in Gqeberha, where the removal of the golf course (see section 3.2.4 for details on the reference landscape, or the landscapes in which golf courses were excluded) in comparison to golf courses' presence in the 'golf course landscape' proved to have insignificant results with regards to the present land cover (0.66 ± 0.19 and 0.65 ± 0.21 respectively) (Wilcoxon Rank Sum Test, W = 36, p = 0.72). Whilst the same was also true for Cape Town and Johannesburg, the golf courses' removal in Gqeberha had a lower impact on the overall land cover, suggesting that these courses in Gqeberha were in fact just in more natural settings.

On average, the golf courses made up 1.17 % (± 0.6) of the 'golf course landscape'. The greatest percentage of a golf course as part of the 'golf course landscape' was that of the Country Club Johannesburg (3.47 %), also the largest golf course of the sample set, whilst the smallest was that of the smallest golf course, Simonstown Country Club (0.17 %). Across the three cities, based off a 0.05 confidence interval, there was an insignificant change in the proportion of green infrastructure (land cover proportion) with the golf course being present and absent from the golf course landscape (Wilcoxon Rank Sum Test, W= 1 414.5, p = 0.448) (Figure 3.7). The same was also true for edge length, number of patches per hectare, greatest patch area, and mean patch area, where p > 0.05 (Figure 3.7).

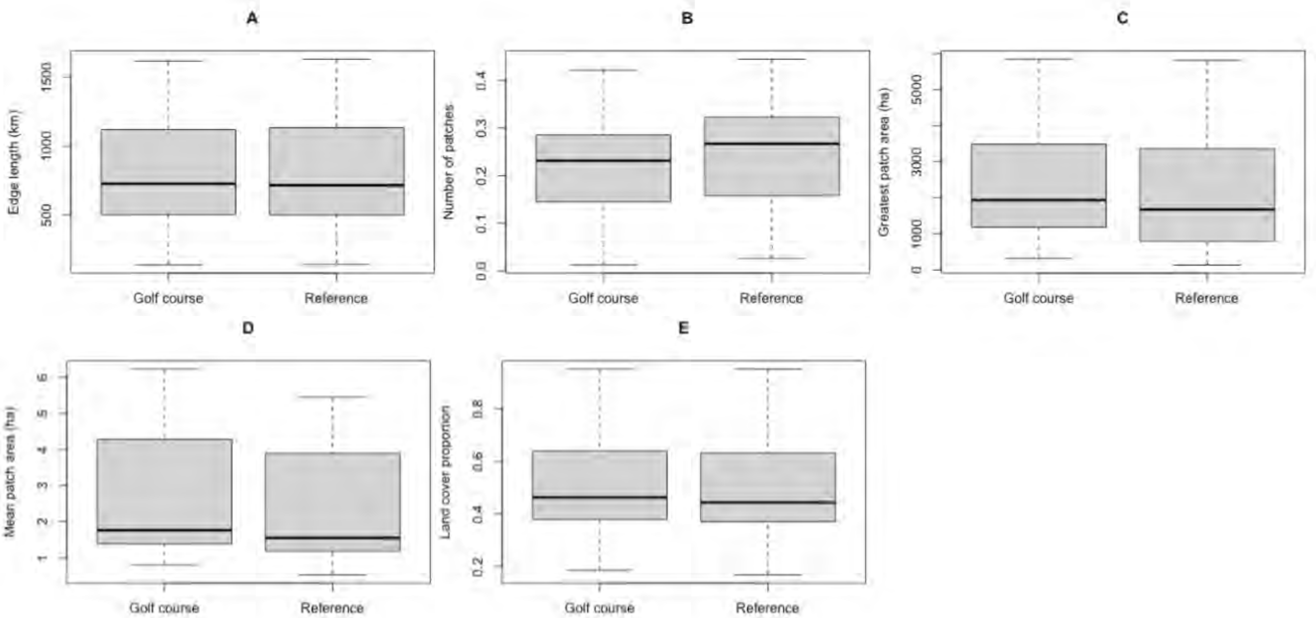

Figure 3.7: Landscape data difference between the 'golf course' and the 'reference' landscape (at the landscape scale) for (A) Edge length (B) Number of patches per ha (C) Greatest patch area (D) Mean patch area and (E) Land cover proportion.

3.4 Discussion

3.4.1. How, and to what extent, are golf courses in South Africa connected to UGI?

As a component of UGI, golf courses form part of the landscape in which they are situated. Whilst their location within these landscapes may or may not grant them any degree of structural connectivity, they still form part of a functioning landscape indicating that other nearby green infrastructure may aid in enhancing golf course biodiversity, whilst also potentially furthering landscape connectivity. This chapter served to contribute to remedy a gap in the present literature, one that addresses the role the surrounding landscape play in aiding and supporting golf courses and their diversity through connectivity and contributing to a discussion about golf course connectivity that is still emerging. The results of this chapter indicate that all golf courses assessed were situated in landscapes that contained other UGI, and were structurally touching one, if not many different, forms of UGI.

Whilst the types, quantity, and quality of UGI (determined by the presence of residential and natural vegetation) varied between each landscape, and within and between the cities, by virtue this presence of UGI means that one needs to consider its potential impact on biodiversity within or between habitats. This study not only noted the presences of UGI within the landscape (landscape scales), all the golf courses analysed were also physically touching surrounding UGI, further illustrating their connectedness.

It is important to consider these initial results in relation to the existing literature, especially those that address the same underpinning taxa around which connectivity is understood. Adler and Jedicke's (2022) review reveals that many studies indicate that birds respond more to habitat composition than landscape configuration. Whilst habitat variables may be more powerful in determining bird diversity, Morelli *et al.* (2018) note that it is not only important to record variables linked to a specific habitat when considering bird diversity, but also the landscapes structure. In their study, across a range of different habitat types, bird species richness responded greatest to the landscape metric 'mean patch size', especially within mixed land uses (Morelli *et al.,* 2018). With many urban settings classified as mixed due to the range of different land uses within them, overall landscape composition and structure was significant for this study.

When examining golf course connectivity, one needs to consider the mix of land uses, both in presence and abundance. Seven land use groups were created, derived from the 73 SANLC classes. It was found that the proportion that these land uses made up varied between landscapes within each city, but also between the cities (see section 3.4.2. for more information on this). To further emphasise the importance for habitat and landscape consideration, the study further addressed the structural connectivity of the golf course, where the level and type of connectivity was recorded. I found that all golf courses were not only situated in landscapes with varying amounts other UGI, but that they were also spatially touching UGI. Whilst factors that impede movement of some species are assumed to be present at most if not all courses (i.e., fences surrounding them), such factors do not limit all species of which birds are one. This indicates for species such as birds, golf courses do not exist as a patch, but are part of a larger mosaic of UGI.

For this study, natural vegetation connected to golf courses made up on average 16 % of the perimeter of the golf course. Since the assessed courses were situated in urban settings, it was no surprise that the proportion urban infrastructure made up was the highest of all the assessed land uses (0.38 ± 0.21). Coinciding with this, was the proportion made up by residential vegetation (0.38 ± 0.24). Whilst often considered detrimental from an ecological perspective, it has been recorded that such land uses also support biodiversity (Sánchez-Sotomayor et *al.,* 2023; Yao *et al.,* 2006). Residential or urban green spaces, constructed and controlled by humans, whether comprised of native or alien vegetation, also provide valuable ecological services. Street and backyard trees support and aid connectivity through enhanced canopy cover and urban forest (Mullaney *et al.,* 2015) whilst also lowering the heat island effect (Ngulani and Shackleton, 2020). Thus, cumulatively, the high presence of both natural vegetation (0.16 ± 0.20) and residential vegetation (0.38 ± 0.24) indicate a high and quality structural connection to UGI in the landscapes. This contribution of residential gardens to connectivity is generally considered a result of the presence of backyard trees that make up the urban forest (Ossola *et al.,* 2019). This form of connectivity through the urban forest has been further noted by Mullaney *et al.* (2015). The high proportion of residential vegetation in the overall landscapes explored therefore suggest a potential impact on biodiversity of golf courses situated in these landscapes.

3.4.2. What is the difference in structural connectivity of golf courses across different South African cities?

With respect to the land use groups created for all three cities, it was found that the proportion that these land uses made up varied between landscapes within each city, but also between the cities. The results illustrate that, between cities, differences were seen across all the regrouped land uses except for residential vegetation, where the only difference was in Gqeberha, due to the high level of natural vegetation found at the landscape scale. Furthermore, within each city (between the different landscapes) there were also large differences in land use proportions.

The presence of structural connectivity, for birds and other species, further indicates a more stable environment with less landscape fragmentation. Beninde *et al.* (2015) notes the importance of large intact areas of green spaces or habitats for this very reason as it allows for more resilient and stable habitats. Despite not being as important for birds due to their mobility, for most taxa, corridors connecting patches are of utmost importance in facilitating movement through landscapes and determining diversity (Beninde *et al.,* 2015). The results show not only the size of the patch or habitat increases, but also the heterogeneity of the actual habitat, further aiding and supporting a wider range of species due to the resources provided (Callaghan *et al.,* 2019).

With the results indicating that both the landscape metrics and structural connectivity measures do not always correspond to the land cover of each city, the issue of landscape context is important. Cape Town, with the second highest vegetated land cover proportionally, had the lowest level of structural connectivity. The same was true for the land cover found within the allocated landscapes (golf course landscapes) where again, Cape Town had the second highest cover, yet the lowest structural connectivity. Both these scales of connectivity are key in describing diversity trends, and as seen here, the measures at these different scales do not always correspond with each other. This illustrates the importance of the consideration of both scales, in line with Morelli *et al.'s* (2018) and Adler and Jedicke's (2022) findings. These measures should thus be considered in conjunction with each other. Given that structural connectivity metrics do not always correspond with city land cover, and that landscape context matters, it is important that future studies of golf course biodiversity pay attention to connectivity, contributing to our understanding of this factor on a global scale.

3.4.3. How does the presence of a golf course affect the connectivity, structure, and function of the broader urban landscape?

Although the results indicate the ways in which the overall landscape may influence golf course biodiversity, the opposite may also be true. Golf courses could also potentially assist in enhancing the connectivity of the surrounding areas.

With golf courses situated in urban landscapes and classified as a particular type of UGI, they further have the potential to aid and enhance the connectivity and biodiversity within landscapes by creating more green spaces, shortening the distance between patches, and connecting patches. As a result, some authors suggest that golf courses' integration and well-planned placement in urban settings could enhance connectivity (Colding, 2007; Nguyen, 2022; Saarikivi, 2013). This is not only due to their size and contribution to UGI, but also because of their vegetation composition. Golf courses' rough or out-of-bound areas often attempt to preserve or retain natural vegetation (Nguyen, 2022). The proportion that the rough or out-of-play areas make up has also increased in more recent golf course designs, making them more ecologically valuable areas in urban settings (Nguyen, 2022). Whilst golf courses are often seen as green deserts for their lack of vegetated areas, Colding (2007) note that on average the rough area, makes up 70% to the golf course area. This indicates resemblances between golf courses and urban gardens, which have a similar proportion of vegetated areas, and may potentially have a similar contribution to urban connectivity. This study therefore hypothesised that golf courses and urban gardens in the three cities may have similar levels of vegetated cover.

This study therefore also paid attention not only to the extent to which golf course are connected to the overall landscape, but whether golf courses may also contribute to connectivity of surrounding areas. Whilst there are debates about whether golf courses are 'green deserts', or if they fragment a landscape (Fox and Hockey, 2007; Petrosillo *et al.,* 2019; Saarikivi, 2016), for the case of this chapter, they are framed as a particular form of UGI, which, if they were not present, their footprint would resemble that of the surrounding areas, which comprised of predominantly grey infrastructure and associated residential infrastructure (turf grass as well as ornamental and non-ornamental plants). Using the approach of golf courses being present and omitted from the landscape, assuming that grey infrastructure would take their place in the latter for the purpose of this study, high levels of structural connectivity were recorded across study sites in South Africa, indicating that golf courses add some connectivity networks within the landscapes addressed.

In terms of golf course landscape composition, it was surprising to find low natural vegetation cover on the 52 golf courses themselves, which made up a mere 7.2 % (± 11.3) of the area. Additionally, the hypothesised similarities between the golf courses and urban gardens were not supported by the evidence in this chapter. Instead, residential vegetation (of which turf grass and other non-native ornamental vegetation is included) of the studied courses made up nearly 90 % of the total golf course area, whereas rough and out-of-play areas make up considerably less in contrast to the 70 % noted by Colding (2007). Residential vegetated areas, or turf grass on the golf courses, may, however, still be beneficial in terms of providing a habitat in which species can live and move, thus supporting some species (of which includes some avian species and microbes) (Sánchez-Sotomayor et *al.,* 2023; Yao *et al.,* 2006). Therefore, these golf courses that are comprised of 90 % residential vegetation may still provide some valuable ecological services. Furthermore, the cumulative presence of natural vegetation, 7.2 ± 11.3 % on the golf course and 16 ± 20 % connected to them, further enhanced the habitat at hand, contributing to the present connectivity.

As connectivity refers to the placement and interaction of habitat patches, this study examined the UGI cover of the three cities and the present land uses when golf courses are present and when they are omitted. It found that Cape Town and Gqeberha's landscapes have substantially greater land cover than Johannesburg, with large difference within each city also being noted. However, no significant differences were noted in terms of the present UGI within these landscapes when golf courses are included and when they are omitted. Perhaps this can be explained by the extent of the vegetated cover in the three cities. With the average area of the vegetated cover in the larger landscape being 3 233.1 ha (± 1 204.1), i.e., already very green, and the average areas of the 52 golf course samples in South Africa of only 69.6 ha (± 34.7 ha) (2.1 % of the total vegetated area), it was no surprise that their presence in the landscape had little result on the vegetated cover.

The three cities studied have a very high proportion of vegetated cover. This vegetation cover (not only public green spaces as the World Health Organisation speak to), calculated as a vegetated cover per person is much higher than the recommendations (on public green space per person) put forward by the World Health Organisation (2010). The assumption of this chapter was that grey infrastructure or the surrounding land uses would occupy the areas golf courses make use of if non-existent as the courses assessed were all situated in the urban landscape with high proportions of grey infrastructure. The results illustrate that the directly surrounding areas were comprised of predominantly grey infrastructure as well as its' associated residential vegetation. This indicates that these grey areas, such as suburbs for example, also house and support an array of green spaces. . These findings are consistent with previous studies that have highlighted the potential conflict between golf courses and green space conservation (Horber, 2021; Spocter, 2017).

In terms of landscape metrics, the golf courses' large size in comparison to the global average (60 ha) as noted by Salgot *et al.* (2012) implies that they would have a greater impact on connectivity. This, however, was not the case, as this study found no statistically significant evidence of this in terms of the analysis of landscape metrics (see Figure 3.7). In addition, the analysis showed no significant change in the edge length of the green spaces measured when the golf courses were present in or omitted from the landscape. This is probably due to the insignificant size of the golf courses in relation to the area of the landscape scale measured as well as the high proportions of vegetated areas found within them. Whilst this may be the case in this study with the chosen metrics, other metrics may give different insights. Furthermore, despite the results indicating that the golf courses do not aid connectivity for bird species at the landscape scale defined by birds' movement, these results may differ for other species at a landscape scale defined by their movements and patterns. This was seen in the presence of coyotes on golf courses in Chicago (Wurth *et al.,* 2020). Whilst golf courses were the least used land use by coyotes due to the present of humans, they still facilitated their movement (Wurth *et al.,* 2020). This suggests further research is necessary to better understand the relationship between golf courses and other taxa.

3.5 Conclusion

Golf courses are an important and complex component of UGI connectivity. In this chapter, the extent to which 52 golf courses in three cities of South Africa were connected to their overall landscapes was assessed. The study examined the green infrastructure and land uses in the three cities, comparing them with and without golf courses present. From the results, it appears that golf courses are structurally connected to the urban landscapes in which they are situated, which may contribute to their ability to house biodiversity. Golf courses may also contribute to the present green infrastructure in the landscape.

While there is a lack of definitive scientific evidence regarding the benefits or harms of golf courses, some authors suggest that golf courses can enhance connectivity and biodiversity in urban landscapes as illustrated in this study (Colding and Folke 2009; Deslauriers *et al.,* 2018;

Nguyen *et al.*, 2020). Golf courses have vegetation, particularly the rough or out-of-play areas, that can preserve and retain ecologically valuable native vegetation. These sites of urban green infrastructure can also provide a supportive habitat for various species, thus supporting and facilitating their movement. However, golf courses may also consist of non-native ornamental vegetation, which can be ecologically harmful, and thus could be seen to fragment the landscape, rather than connecting it. This notion of fragmenting a landscape is not uncommon, nor is the idea that they may be a 'green desert' (Fox and Hockey, 2007; Petrosillo *et al.,* 2019; Saarikivi, 2016). Thus the context of the landscape in which the golf course is situated is of utmost importance to consider for both a biodiversity perspective and a connectivity one.

Despite the study not finding any significant difference in the contribution of golf courses to the vegetated cover in the landscape, golf courses can provide valuable ecological services and contribute to connectivity and biodiversity in urban landscapes. However, their impact depends on various factors, including the vegetation composition, design, management, and scale at which they are addressed. It is thus suggested that other studies unpacking golf courses contribution to connectivity be undertaken, across a range of different courses, and in different setting. In contrast to the smaller proportion the rough accounted for in the 52 courses in this study, Colding (2007) reported that golf courses rough can make up, up to 70 % of their total area suggesting a greater contribution to connectivity and landscape functioning. Thus a range of golf courses consisting of different habitat compositions should also be unpacked in future studies.

As there are already high levels of urban green infrastructure (UGI) found across South Africa, specifically the cities chosen for this study, there is a need for similar assessment to be conducted in more urbanized contexts. There is an abundance of other cities within the Global South context that could be assessed. In addition, this study only referred to a few connectivity metrics and land uses, which were grouped together in certain cases.

This chapter focused on connectivity of golf courses, in terms of the extent to which golf courses were connected to the overall landscape and whether golf courses themselves contribute to/enhance connectivity. When one addresses urban golf courses, it cannot simply be noted that the courses considered may act as hotspots for diversity without assessing their urban context. This study illustrated that the different urban contexts hosted a range of UGI and all golf courses were connected to various extents.

Chapter 4: Bird diversity

4.1 Introduction

The need to preserve natural and urban green spaces becomes more urgent with increasing urbanisation across the globe. Within the urban context, green spaces, ranging from parks, green belts and golf courses, and their contribution to urban and peri-urban biodiversity, are significant (Lepczyk *et al.,* 2017). The benefits of urban green spaces to human wellbeing and ecosystem services (provisioning, cultural and regulating) area well known (Jennings *et al.,* 2016). At present, many cities, especially in the Global South, have insufficient and inequitable public green spaces to meet the needs of their citizens due to densification and the legacy of past racial segregations (Haaland and van Den Bosch, 2015; Venter *et al.,* 2020). Moreover, what is present is often too small to support significant biodiversity and associated ecosystem services (Jarrett and Shackleton, 2017).

Golf courses are generally not associated with promoting biodiversity and ecosystem services. Indeed, many view them as detrimental to the environment because of their contribution to land transformation and water consumption (Fox and Hockey, 2007; Petrosillo *et al.,* 2019; Worster, 2008). However, as is evident in the findings of Saarikivi *et al.* (2013), Sorace and Visentin (2007) and Lonsdorf *et al.* (2021) they do provide some ecological services such as breeding grounds for some protected species, reducing the heat island effect and more. Golf courses may also contribute to reducing the urban heat island effect (Ngulani and Shackleton, 2020). Given these contrasting perspectives, it is often difficult to fully ascertain the value of an area, as the uses and users constantly change, along with their views and assigned values. There is also significant interplay between various environmental factors at different scales which is important to consider when attempting to conserve biodiversity in urban spaces (Beninde *et al.,* 2015; Nooten *et al.,* 2018; Sala *et al.,* 2000).

The extent to which golf courses contribute to biodiversity therefore deserves further exploration. Observations of birds on golf courses and the surrounding urban landscapes can illustrate the effects of golf courses on biodiversity to some extent, as well as the connectivity between different urban landscapes. The value allocated to biodiversity is not only inherent but also instrumental in urban landscapes, for the integrity and stability of the ecosystem, and preventing regime shifts (Folke *et al.,* 2004). For instance, birds play crucial roles not only in seed dispersal and pollination, but are also important components of trophic webs: some species are top-level predators and others play important mid-level roles (consumers), important for ecosystem integrity (Endangered Species, 2011, Faeth *et al.,* 2005). Their positions in trophic webs indicate their roles in creating the structure and evenness of avian, and overall, biodiversity. Birds are thus considered a sound biodiversity and bio indicator for other taxa, environmental health and ecological change (Mekonen, 2017; Tanner and Gange, 2005).

However, Lee *et al.* (2021) claim that, despite the general decline in animal species diversity and richness with increasing urbanisation, some taxa, such as birds, show the opposite due to the increase in non-native species and widespread bird feeding by residents (Lee *et al.,* 2021). Despite often suppressing or limiting other species, non-native birds may have a positive impact on people, through the pigeon paradox, i.e., how they connect people to nature and may in fact consequently enhance conservation efforts (Lee *et al.,* 2021).

Various authors have explored the biodiversity of golf courses using birds as a biodiversity indicator. Culbert *et al.* (2013) indicate a relationship between avian species richness and tree cover on golf courses due to the provision of nesting and perching opportunities. The nesting and perching opportunities (emerging because of tree abundance and canopy cover) are similar in residential areas and open green spaces as noted by Ossola *et al.* (2019), suggesting similar levels of avian diversity in these areas. However, higher extents of trees and canopy cover in golf courses as opposed to the urban-agricultural fringe, as well as a positive relationship between golf courses and avian diversity (Sorace and Visentin (2007). Sorace and Visentin's (2007) study in Italy also records more avian species, including some of conservation concern, and sensitive to fragmentation, on golf courses compared to the surrounding area, although the authors indicate that the golf courses may not be responsible for this trend. Colding and Folke's (2009) literature review indicates that 64 % of papers surveyed show that golf courses have more biodiversity than the surrounding green areas with an even higher biodiversity than the urban landscape. Finally, Gallo *et al.* (2017) note a significant difference in Gamma diversity (γ-diversity) and Beta diversity (β -diversity) between golf courses, cemeteries and urban parks, and natural areas. Natural areas had the greatest diversity and richness, with golf courses and cemeteries following. The urban parks were found to have the lowest diversity and richness (Gallo *et al.,* 2017).

Previous studies assessing the biodiversity of golf courses have compared them to surrounding agricultural or green areas. This is important in understanding the effects of golf courses on biodiversity using natural or semi-natural areas as a baseline. However, these studies at large have ignored the urban context where golf courses often fall somewhere within the spectrum of natural and urban spaces. As seen in Ossola *et al.* (2019), ties between urban and residential settings and golf courses can be drawn. This was seen in the structure and composition of the blue-green infrastructure across these spaces, where they found that residential areas provide more tree canopy cover than all other urban areas excluding open green spaces and golf courses. Moreover, Aida *et al.* (2016) indicate positive relationships between the presence of vegetation and water bodies in urban green spaces and avian biodiversity. This illustrates how structural and compositional diversity of the vegetation is key when assessing biodiversity. This is further supported by Shwartz *et al.* (2008) noting a decrease in richness of all bird guilds with increasing lawn cover in urban parks.

The ability of golf courses to support biodiversity has usually been addressed in isolation from their surroundings. Yasuda and Koike (2006) note the difference in the presence of faunal and floral species between urban and rural golf courses: urban courses housed mostly naturalised, exotic plant species and urban birds (*Corvus*), whilst the rural golf courses housed more forest plant species. However, these two areas, urban and rural, were addressed without considering their surroundings and connectivity to other Urban Green Infrastructure (UGI), an oversight that might affect the findings reported. Connectivity is likely to be important for a holistic study of the biodiversity of golf courses in comparison to surrounding urban areas. It has been noted that high habitat heterogeneity, a result of moderately disturbed landscapes (i.e., urban settings housing UGI) may provide high levels of resources (Callaghan *et al.,* 2019). It was further noted that the mix of land uses addressed should also be considered alongside landscape metrics (Morelli *et al.,* 2018). As reported in Callaghan *et al.* (2019), bird diversity and the urban gradient do not follow a linear pattern, but diversity rather peaks in moderately disturbed settings. This further illustrates the importance of the landscape context, where heterogeneity, created by the presence of UGI is crucial.

Finally, literature from South Africa regarding the biodiversity of golf courses is limited. Existing research tends to address management practices such as the presence and composition of woody vegetation, species management, the case of the Egyptian geese on golf courses, and perceptions of Egyptian geese by golfers and managers (Cock, 2008; Little and Sutton, 2013;

Mackay *et al.,* 2014; Jarrett and Shackleton, 2017). Scant literature addresses the extent to which golf courses support biodiversity, especially fauna, including avifauna. This is of concern in Cape Town, situated in a Global Biodiversity hotspot, as the introduction of alien plant species has been at the expense of the native flora and fauna (Anderson *et al.,* 2021). Moreover, according to Jarrett and Shackleton (2017), this is not uncommon, where roughly 40 % of trees on golf courses in the Eastern Cape of South Africa are non-native.

Within the above context, this chapter sought to assess the avifaunal diversity of Cape golf courses in Cape Town by addressing three key questions: 1) How and to what extent does the avifaunal diversity of golf courses differ from that of the surrounding urban landscape? 2) Is there any relationship between the extent and composition of vegetation of golf courses and bird diversity? 3) Does the connectivity of golf courses to other urban green infrastructure (UGI) affect the avifaunal diversity of golf courses?

4.2 Methods and Materials

This study initially identified all golf courses within the boundaries of the City of Cape Town. Of the 18 courses, three were links courses (located by the coast, characterised by their open layout and sparse vegetation), and 15 were parklands (resembling urban parks due to their incorporation of trees, vegetation, and waterbodies).

These consisted of both 18 - and nine-hole courses. Drawing from Tanner and Gange (2005), this chapter focused on the avian diversity of urban areas that fall within 0.5 km of golf course boundaries in comparison to the biodiversity found on golf courses. Whilst all golf courses were initially appraised, only the courses where access was granted were analysed (10).

4.2.1 Bird biodiversity

All golf courses situated in the City of Cape Town were demarcated using QGIS, along with the surrounding urban areas. In cases where courses were situated in a residential estate, the living areas were removed from the course boundaries. These areas were excluded from all sampling (i.e., the avifaunal diversity sampling on the golf courses and the urban areas) because they were not golf courses per se. Furthermore, because they were formally part of the golf estate, where they were managed the same way, and thus were excluded from the urban area sampling as well. Moreover, policies are in place that encompass and group both the golf course and residential land uses of golfing estates in the Western Cape of South Africa (Department of Environmental Affairs & Development Planning, 2005).

The surrounding areas were demarcated around each golf course, using a 0.5 km buffer around each course. Additionally, between the golf course and surrounding area (urban area) a buffer was allocated (50 m) to limit any sight overlap between the golf courses and the surrounding urban areas. Within the demarcated urban areas, UGI was avoided where possible and excluded from the demarcated area, to limit the sampling to areas dominated by grey infrastructure. Areas characterised by large quantities green infrastructure, such as green belts, nature reserves and national parks, were excluded as these areas appear to aid species with functional traits, essential for ecosystem function (Maseko *et al.,* 2019). This limited the urban setting sampling points to areas dominated by grey infrastructure. This was done to allow for comparison between bird diversity noted in green, grey infrastructure within an urban extent.

The Variable Circular Plot (VCP) method was used. The VCP, originally described by Reynolds *et al.* (1980), is a method whereby random points are allocated to a study site, at which radial, visual and audio records of species making use of the area are made. Tanner and Gange (2005) describe species making use of an area as those that are engaged in one or more of: feeding, nesting, perching and breeding. This definition was adopted for this study, along with species circling directly above searching for prey (feeding) for raptors. The VCP method, also employed by Tanner and Gange (2005), only made use of sight recordings and not sound, which is also the approach chosen for this study. This decision is due to the limited accuracy with which I can identify birdcalls.

The VCP method does not assume all species will be recorded and that the observer can miss up to 50 % of the individuals, though still able to obtain a reliable density (Tanner and Gange, 2005). Moreover, the VCP method is considered ideal in patchy habitats, a characteristic of golf courses due to their differentiation into freeways, roughs and water features (Reynolds *et al.,* 1980; Tanner and Gange, 2005). Tanner and Gange (2005) demarcated the sampling points to be far enough apart to avoid multiple recordings of the same individuals. Employing this method, this study adopted a 200 m distance between points (or 100 m between sampling point and furthest possible sighting of a bird) as was used by Tanner and Gange (2005) and Maseko *et al*. (2020). This distance (100 m) was tested prior to the study, and deemed sufficient, while accurate enough to sight species through use of binoculars with a magnification of 8 × 10 mm. At each point, five minutes were spent identifying bird species after a two-minute resting period (Tanner and Gange, 2005).

Because golf courses differed in size, ranging from 10.2 ha to 93.8 ha, the number of sampling points per course was proportional to the golf course size. Points were allocated by placing the maximal number of sampling points that could fit on each course, whilst being restricted to being greater or equal to 200 m apart from each other, and away from the course perimeter. Once these points were allocated to each course, the same number of points was allocated to their corresponding urban area. These points were selected using the 'random points in extent' tool on QGIS. The number of points per golf course ranged from 10 to 23.

Data collection took place during peak summer months in Cape Town (January through February), when avian diversity is greatest in terms of both higher local (site specific) and mean (average across all sites) richness (Dybala *et al.,* 2015). It is likely that summer surveys would represent a larger overall species list, in comparison to winter ones. Data was collected between of 6 am and 10 am (Beaugeard *et al.,* 2021). This time, namely sunrise to towards mid-morning (10 – 10:30 am), encompasses the period of greatest bird activity (Robbins, 1981). With the total number of sampling points for the golf course and urban areas ranging from 10 to 23, the time taken to sample a site ranged from 70 minutes to 161 minutes accommodating a five-minute sampling time frame and a two-minute resting period per point.

Due to the variation in course sizes (and corresponding number of points sampled), sampling occurred over one or two days. Smaller courses and their corresponding areas were all sampled in the same day. To standardise the sampling over a multi-day period, days as close together, with no cloud cover, similar moderate temperatures, limited wind and without rain were chosen. This standardisation was also applied to the sampling between the courses. Avifaunal sampling took place twice per course and surrounds during the summer months and the average counts were calculated. For the courses and urban areas that were sampled on the same day, the order in which the golf course and urban areas were measured in relation to each other was randomised so to vary the time in which they are recorded (i.e., between 6 am and 10 am) (Beaugeard *et al.,* 2021).

While in the field, the location of each of the VCP points was obtained using a handheld GPS cellular app. For the urban areas, all GPS coordinates were entered into Google Earth, where, using the street view, the residential address or road name was obtained. These areas were found using Google Maps. The owners of all residential properties accessed as part of the study were contacted prior to property access. Where access was denied, the closest property to the GPS point was then accessed. All birds were recorded to species level to allow for diversity, richness and evenness to be calculated for each of the courses, as well as in the neighbouring urban areas. Diversity was calculated using the Shannon-Weiner Diversity Index (Equation 4.1), which quantifies species variety by considering both the abundance and evenness of the species present. Richness refers to the total number of unique species observed in a given area, providing a simple count of species without regard to their relative abundance (Heip *et al.,* 1998). Evenness measures how evenly individuals are distributed across the species present, indicating whether a community is dominated by a few species or if there is a balanced distribution of species abundances (Heip *et al.,* 1998). For species that could not be identified in the field, post-field work identification took place by analysing images captured during digital data collection (on a Cannon 5D mark 3 and a 600 mm Cannon lens, ideal for wildlife photography and capturing birds).

$$\text{Shannon Index (H)} = -\sum_{i=1}^{S} pi \ln pi \ldots \text{ EQ.4.1}$$

Equation 4.1: The Shannon-Weiner Index, where H represents diversity, p is the proportion of the total number of individuals (N) a species makes up, ln is the natural log, Σ is the sum of the calculations, and s is the number of species.

As the literature points towards a decline in animal species diversity with increasing urbanisation (Batary *et al.,* 2017, Faeth *et al.,* 2011, Fenoglio *et al.,* 2020), differences in the presence of urban adaptors between the two areas was also measured. This was done using Lee *et al.* (2021) classification scheme of South African bird species, where species were classified based on their feeding guilds and their categorisation an ecosystem engineer, habitat specialist or urban adaptor.

4.2.2 Vegetation Composition and Connectivity

To help interpret the bird biodiversity data, a range of attributes were recorded at the golf courses and the urban areas. At both golf courses and urban areas, plant species were recorded in a similar manner to the avian species with 10 points randomly allocated using the 'random points in extent' tool in QGIS (Jarrett and Shackleton, 2017). Each point consisted of 10 m × 10 m plots.

With a correlation between vertical habitats and avifaunal diversity (MacArthur, and MacArthur, 1961), a range of variables that describe the size and abundance of vertical habitats (trees) were selected, namely total tree count, and Diameter at Breast Height (DBH) of the recorded trees (Aida *et al.,* 2016; Berg, 1997; Culbert *et al.,* 2013; Lee and Rotenberry, 2005). Since Dures and Cumming (2010) observe an increase in avian species richness with the decrease in non-native tree species in Cape Town, the recorded trees were also classified as either indigenous or alien (non-native). Canopy/aerial cover as a percentage estimate of plot area and woody cover (the area of ground covered by wooded species and the wooded part of the flora) area was recorded. Furthermore, and in addition to the comparison of golf courses to grey infrastructure, the wealth gradient and its relationship to biodiversity of golf courses was also assessed. This is because vegetation is especially prominent in Cape Town's wealthiest areas (Venter *et al.,* 2020). The monthly income per suburb in which the course was situated was obtained via the City of Cape Town's online platform (City of Cape Town, 2013).

Additionally, other factors that affect avifaunal diversity as described by Mellink *et al.* (2017) were incorporated. The authors describe the importance of herbaceous species in affecting avian diversity. The number of herbaceous species within each plot was recorded, along with the total herbaceous cover (percent) (Berg, 1997; Canedoli et al., 2018; Jarrett and Shackleton, 2017). Species abundance was assessed by counting individuals within the plot, followed by taking an average across all the plots.

The DBH data collection followed the same procedure of taking average measurements across all the plots. The diameter was measured using a tape measure and these readings were averaged across the plots. Along with these factors, others that influence avian biodiversity were obtained from the connectivity study (Chapter 3) namely the extent of each type of land cover: water cover, bare cover, natural vegetation cover, residential vegetation cover, urban cover, and other. Other metrics from the connectivity study (Chapter 3) were included that are also considered to aid bird diversity. Feeding into patch size, Maseko *et al.* (2020) noted the importance of the size of intact forest fragments. These were: the total area of natural vegetation, land cover proportion, edge length, number of patches (of natural vegetated areas), mean patch area and greatest patch area of said naturally vegetated. As outlined in the Chapter 3, these metrics cover a wide range of connectivity aspects that address both functional and structural connectivity.

4.2.3 Data analysis

Prior to any statistical analyses, all data was tested for normality and homogeneity of variances. Where necessary, data was root transformed. The Shannon-Weiner diversity indexes within each area (golf course or urban area) were compared using a repeated measures analysis of variance (ANOVA). This approach was also employed by Tanner and Gange (2005). Species abundance, richness and evenness were calculated along with the difference in presence of urban adaptors. These calculated units were also tested using an ANOVA. Significance testing was performed on R studio, version 4.31.

A multiple linear regression, addressing the factors that potentially affect biodiversity, was performed. The multiple regression of golf course and urban area data together was undertaken alongside a dummy variable, distinguishing the two different areas, where golf courses were issued a value of 1 and urban areas a value of 0, differentiating the two.

Included in the multiple regression was the measure of structural connectivity measured as the proportion of UGI the make up the perimeter of each golf courses (refer to Chapter 3). In addition to this measure of connectivity, all the measured site variables along with connectivity variables were considered. The variables used totalled 19, and were reduced to 18 through the use of a correlation matrix. All variables with the exception of structural connectivity were included in the matrix as to ensure it was not removed in the process. This process was followed to guarantee its assessment in the regressions. Structural connectivity at the intermediate scale was measured as the proportion of the golf courses perimeter occupied by surrounding UGI, as outlined in Chapter 3 section 3.2.3. As there was more than one landscape metric (seven) at the landscape scale, they were all included in the matrix. This was also computed on R studio. The dummy variable indicates whether the area (golf course or urban area) is of significance for determining the avifaunal diversity measured. It was important to address each area independently (as two independent samples) and thus an additional two multiple regressions (one for each area) were conducted. Doing so required a reduction of independent variables as well.

The 18 starting variables were reduced to eight using a correlation matrix (Figure 4.1), where individual variables were ranked according to the number of other variables with which they were correlated using a correlation coefficient of 0.7, indicating a strong relationship (Ratner, 2009). As five variables were not correlated with any others, they were the first included. These were ‘other cover’, ‘urban cover’, 'alien tree count’, ‘percent herb cover’ and ‘percent canopy cover’. Additionally, there were another six variables that had one correlation. These were reduced to four, of which two were correlated to each other and one of the two was removed at random (‘water cover’, ‘bare cover’, ‘residential vegetation’ and ‘natural vegetation’). Of the remaining four, two were selected at random along with the measure of structural connectivity providing a total of eight variables. The additional two selected variables were those of ‘natural vegetation’ and ‘residential vegetation’. These were used for two independent multiple linear regressions, where again normality was tested.

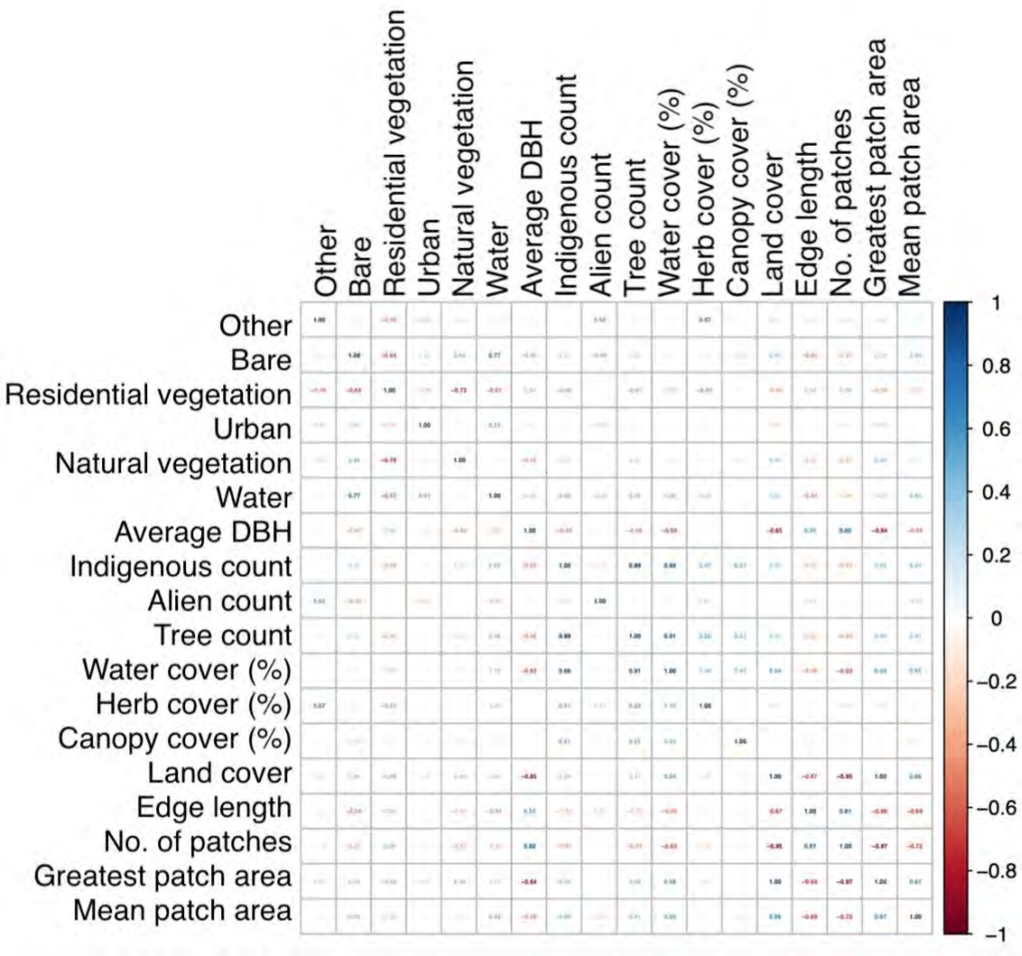

Figure 4.1: Correlation matrix between the independent variables.

The use of the correlation matrix for variable reduction was chosen over other methods, as it considered all variables in relation to all others in a linear form as individual pairs (Ratner, 2009). This equal consideration allowed for an accurate, holistic list of variables to be reduced without issues such as collinearity. A cluster analysis was incorporated to categorise the analysed courses into 'more' and 'less' urban. Distance matrices were created using the 'vedgits' function on R Studio, whereafter hierarchal clustering was performed using the 'hclust' function (Kirichenko-Babko *et al.,* 2021). The Silhouette method and Mantel's statistic were then used to justify the selected number of clusters used in the analysis.

Considering the additional factors for determining biodiversity included in the study, a linear regression using R Studio was conducted to address the relationship between plant species present, ground cover, diameter at breast height, plant canopy cover, the connectivity of the courses to other UGI, water features (size and abundance) and the recorded avian species. The relationship between the age of a golf course and vegetation (native or alien), was assessed through a Spearman's correlation test.

Lastly, the data on connectivity of the golf courses was compared to both golf course characteristics, and the dispersal abilities of a select range of birds (See Chapter 3, Section 3.2.1). This was performed to assist with the assessment of how golf courses aid functional connectivity of birds and how the golf course characteristics influence/affect the possible trends. Data was tested for normality and homogeneity of variance and where appropriate square root transformations were made.

4.3 Results

4.3.1 Site composition and differences

Across the 10 sampled golf courses and their corresponding surrounding areas, a total of 114 bird species were identified, represented by 9 192 individuals, with 5 064 individuals found on the golf courses and 4 128 individuals in the urban surrounding areas. There was a higher species richness on the golf courses (98) than the urban areas (78). Of these species recorded, the most common ones sighted are tabulated below, comprising of the top twenty species per site (Table 4.1). A total of 41 species were only sighted on the golf courses, compared to only 16 in the surrounding urban areas (Table 4.2). For all species recorded at each site, see appendix (Table 3).

Table 4.1: The most prominent (top twenty) species found in the two different areas (golf course and urban) along with the percentage of the total count they make up.

Golf Course			**Urban**		
Species	**No.**	**%**	**Species**	**No.**	**%**
Goose, Egyptian (*Alopochen aegyptiaca*)	951	18.8	Starling, Common (*Sturnus vulgaris*)	863	20.9
Ibis, Hadeda (*Bostrychia hagedash*)	558	11	Gull, Hartlaub's (*Chroicocephalus hartlaubii*)	487	11.8
Guineafowl, Helmeted (*Numida meleagris*)	401	7.9	Dove, Rock (*Columba livia*)	396	9.6
Starling, Common (*Sturnus vulgaris*)	389	7.7	Starling, Red-winged (*Onychognathus morio*)	222	5.4
Gull, Hartlaub's (*Chroicocephalus hartlaubii*)	266	5.3	White-eye, Cape (*Zosterops virens*)	204	4.9
Canary, Cape (*Serinus canicollis*)	259	5.1	Dove, Laughing (*Spilopelia senegalensis*)	202	4.9
Duck, Yellow-billed (Anas undulata)	172	3.4	Pigeon, Speckled (*Columba guinea*)	160	3.9
White-eye, Cape (*Zosterops virens*)	167	3.3	Crow, Pied (*Corvus albus*)	141	3.4
Stilt, Black-winged (*Himantopus himantopus*)	129	2.6	Stilt, Black-winged (*Himantopus himantopus*)	136	3.3
Lapwing, Blacksmith (*Vanellus armatus*)	121	2.4	Sparrow, Cape (*Passer melanurus*)	129	3.1
Fiscal, Southern (*Lanius collaris*)	117	2.3	Ibis, Hadeda (*Bostrychia hagedash*)	108	2.6
Dove, Ring-necked (*Streptopelia capicola*)	114	2.3	Dove, Ring-necked (*Streptopelia capicola*)	106	2.6
Starling, Red-winged (*Onychognathus morio*)	103	2	Tern, Sandwich (*Thalasseus sandvicensis*)	105	2.5
Wagtail, Cape (*Motacilla capensis*)	99	2	Dove, Red-eyed (*Streptopelia semitorquata*)	103	2.5
Coot, Red-knobbed (*Fulica cristata*)	97	1.9	Guineafowl, Helmeted (*Numida meleagris)*	78	1.9
Pigeon, Speckled (*Columba guinea*)	95	1.9	Goose, Egyptian (*Alopochen aegyptiaca*)	73	1.8
Cormorant, Reed (*Microcarbo africanus*)	92	1.8	Sparrow, House (*Passer domesticus*)	69	1.7
Swallow, White-throated (*Hirundo albigularis*)	54	1.1	Sunbird, Southern Double-collared (*Cinnyris chalybeus*)	57	1.4
Dove, Red-eyed (*Streptopelia semitorquata*)	52	1	Wagtail, Cape (*Motacilla capensis*)	42	1
Weaver, Cape (*Ploceus capensis*)	49	1	Weaver, Cape (*Ploceus capensis*)	38	0.9

Table 4.2: Species unique to the golf courses and the urban areas (Bird names according to Lee *et al.*, 2021).

Only on Golf course		**Only in Urban area**
American Pekin *(Anas platyrhynchos domesticus)*	Heron, Grey *(Ardea cinerea)*	Apalis, Bar-throated *(Apalis thoracica)*
Batis, Cape *(Batis capensis)*	Honey-buzzard, European *(Pernis apivorus)*	Barbet, Acacia Pied *(Tricholaema leucomelas)*
Bishop, Yellow *(Euplectes capensis)*	Honeyguide, Lesser *(Indicator minor)*	Bunting, Cape *(Emberiza capensis)*
Bokmakierie *(Telophorus zeylonus)*	Kestrel, Lesser *(Falco naumanni)*	Buzzard, Common (Steppe) *(Buteo vulpinus)*
Chaffinch, Common *(Fringilla coelebs)*	Kestrel, Rock *(Falco tinnunculus)*	Crow, Cape *(Corvus capensis)*
Cisticola, Cloud *(Cisticola eximius)*	Kingfisher, Pied *(Ceryle rudis)*	Eagle, Verreaux's *(Aquila verreauxii)*
Cisticola, Levaillant's *(Cisticola tinniens)*	Longclaw, Cape *(Macronyx capensis)*	Egret, Western Cattle *(Bubulcus ibis)*
Cormorant, Reed *(Phalacrocorax africanus)*	Moorhen, Common *(Gallinula chloropus)*	Fish-eagle, African *(Haliaeetus vocifer)*
Cormorant, White-breasted *(Phalacrocorax lucidus)*	Mousebird, White-backed *(Colius colius)*	Hobby, Eurasian *(Falco Subbuteo)*
Crombec, Long-billed *(Sylvietta rufescens)*	Night-Heron, Black-crowned *(Nycticorax nycticorax)*	Sparrow, Southern Grey-headed *(Passer diffuses)*
Dove, Lemon *(Turtur chalcospilos)*	Petronia, Yellow-throated *(Petronia superciliaris)*	Sunbird, Orange-breasted *(Anthobaphes violacea)*
Duck, African Black *(Anas sparsa)*	Plover, Grey *(Pluvialis squatarola)*	Swallow, Barn *(Hirundo rustica)*
Duck, Maccoa *(Oxyura maccoa)*	Prinia, Karoo *(Prinia maculosa)*	Swift, Little *(Apus affinis)*
Duck, Muscovy *(Cairina moschata)*	Siskin, Cape *(Crithagra mozambica)*	Tern, Sandwich *(Thalasseus sandvicensis)*
Duck, Yellow-billed *(Anas undulata)*	Sparrowhawk, Rufous-chested *(Accipiter rufiventris)*	Tern, Swift *(Chlidonias niger)*
Falcon, Peregrine *(Falco peregrinus)*	Sunbird, Amethyst *(Chalcomitra amethystine)*	Woodpecker, Olive *(Dendropicos griseocephalus)*
Goose , Domestic *(Anser anser domesticus)*	Swamp-warbler, Lesser *(Acrocephalus gracilirostris)*	
Goose, Spur-winged *(Plectropterus gambensis)*	Tern, Common *(Sterna Hirundo)*	
Grebe, Little *(Tachybaptus ruficollis)*	Thick-knee, Water *(Burhinus vermiculatus)*	
Greenbul, Sombre *(Andropadus importunes)*	Tit-babbler, Layard's *(Sylvia layardi)*	
Harrier-Hawk, African *(Polyboroides typus)*		

Of the two most common species and urban adaptors identified in both sites, only the Common Starling (*Sturnus vulgaris*) is non-native. Overall, there were four non-native urban adaptors species (Common Starling, House Sparrow, Muscovy Duck and Indian Peafowl), with all present on the golf courses and three in the urban areas.

Between the golf courses and the corresponding urban areas, there were differences in the most common species present. The Egyptian Goose (*Alopochen aegyptiaca*) was the most common species on the golf course with a total of 951 individuals. Despite also being present in the urban surrounds, there were far fewer, a mere 73 individuals. The most common species in the urban area, the Common Starling (*Sturnus vulgaris*) totalled 863. Furthermore, the golf courses had fewer urban adaptors than the urban areas with 1 476 individuals compared to 2 284. Among these, the Common Starling made up roughly 38% of all urban adaptors in the urban areas. This difference, however, was not statistically different (Welch Two Sample t-test: $t = 1.28$, $df = 16.92$, $p = 0.219$). The proportion of the most common species equates to roughly 30 % of all individuals on the golf course and over 55 % in the urban areas.

Twenty urban adaptor species were recorded, with 19 found in the urban areas, and 18 on the golf courses. It was only the Muscovy Duck that was seen on the golf courses and not in the urban areas, whilst the Barn Swallow (*Hirundo rustica*) and Little Swift (*Apus affinis*) were the two seen in the urban areas and not the golf courses (Table 4.3). Differences in the presence of feeing guilds were also noted between the two areas where it was noted that apart from the birds with a mixed diet, insectivores were the most prominent on the golf courses (17.4 %), whilst Granivore were the biggest feeding guild in the urban settings (30.9 %) (Table 4.4).

Table 4.3: The urban adaptor species (common names) found between the two areas.

Golf course		Urban area	
Dove, Laughing	Pigeon, Speckled	Dove, Laughing	Sparrow, House*
Dove, Red-eyed	Sparrow, House*	Dove, Red-eyed	Starling, Common*
Dove, Rock	Starling, Common*	Dove, Rock	Starling, Red-winged
Duck, Muscovy*[GC]	Starling, Red-winged	Gull, Kelp	Swallow, Barn[UR]
Gull, Kelp	Thick-knee, Spotted	Ibis, African Sacred	Swift, Little[UR]
Ibis, African Sacred	Thrush, Olive	Ibis, Hadeda	Thick-knee, Spotted
Ibis, Hadeda	Wagtail, Cape	Kite, Yellow-billed	Thrush, Olive
Kite, Yellow-billed	Whydah, Pin-tailed	Masked-weaver, Southern	Wagtail, Cape
Masked-weaver, Southern		Peafowl, Indian*	Whydah, Pin-tailed
Peafowl, Indian*		Pigeon, Speckled	

[Note: Introduced species represented by an *, Species only found on golf courses and urban areas represented by [GC] and [UR], respectively]

Table 4.4: The total number of species made up by each feeding guild along with the percentage that each guild makes up of the total species count for each area.

Class	**Golf course**		**Urban**	
	No. of individuals	**% of total species count**	**No. of individuals**	**% of total species count**
Vertebrate prey	32.0	0.6	149.0	3.6
Insectivores	880.0	17.4	239.0	5.8
Frugivore	40.0	0.8	18.0	0.4
Granivore	703.0	13.9	1 276.0	30.9
Pollinator	78.0	1.5	77.0	1.9
Piscivore	174.0	3.4	129.0	3.1
Mixed diet	2 847.0	56.2	2 083.0	50.5
Other	310.0	6.1	157.0	3.8

4.3.2 Avifaunal Diversity

There was no significant difference in the avifaunal evenness between the two areas (t = 0.32, p = 0.75). The ten golf courses had significantly higher richness than the urban areas (t = 4.35, p < 0.0001). The same was true for the avifaunal diversity, where the Shannon-Wiener diversity index (H) for the golf course was significantly higher to urban areas (t = 2.25, p = 0.038) (Figure 4.2). Not only were the means different, but all golf courses aside from three had greater diversity according to the Shannon-Weiner diversity index (Table 4 in Appendix).

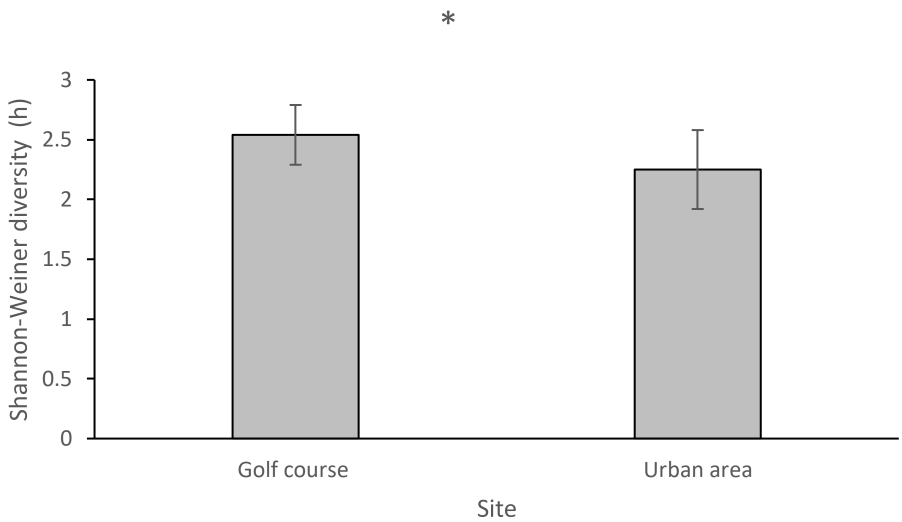

Figure 4.2: Shannon-Weiner diversity index (h) at each site (golf course and urban area) (Signif.codes: <0.05‘*’ >0.05‘.’ >0.1 ‘ ’).

Whilst the golf course proved to have a lower water cover (1.8 %) to that of the urban areas (4.2 %), some freshwater features were not present on the land use maps used, despite all golf courses having fresh water features of various sizes. This difference in presence of water bodies between the golf courses and their neighbouring urban areas were however insignificant for both the SANLC and survey data ($t = 1.71$, $p = 0.12$ and $t = 0.102$, p-value = 0.92 respectively). However, when all aquatic species were removed from the avifaunal data set, the significances noted in diversity between golf courses and urban areas did not remain, suggesting that the presence of water bodies on golf courses is important for bird biodiversity (Figure 4.3).

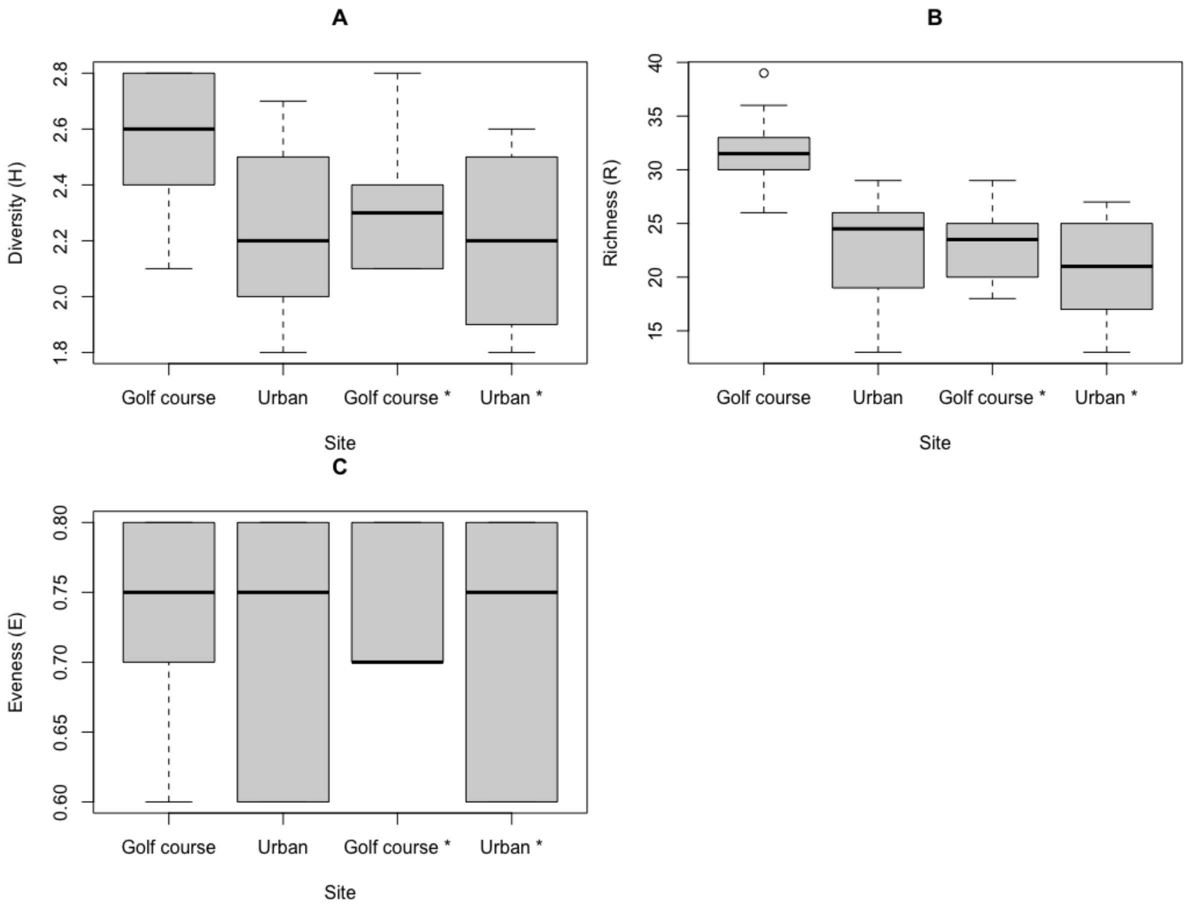

Figure 4.3: Box plot of the mean in A) Diversity (H), B) Richness (R) and C) Evenness (E) of the golf courses and urban areas as well as the mean in Diversity (H), Richness (R) and Evenness (E) between the golf courses and urban where waterfowl were not included, represented by '*'.

4.3.3 Land use differences

Results of the measurement of independent variables in relation to the Shannon-Weiner Diversity index indicated that, although residential vegetation was a prominent land use in residential areas and golf courses, there were large differences in the size of land uses between the urban areas and golf courses. Residential vegetation (turf grass included) dominated the golf course landscape (88 % cover) whilst making up 42 % of land used in the urban areas ($t = 5.8257$, $p < 0.01$) (Table 4.5). Whilst there was a greater proportion of grey infrastructure in the urban areas than on the golf courses ($t = 2.1909$, $p = 0.047$), the total average proportion of grey infrastructure in urban areas was low (12 % cover).

Table 4.5: The values of each independent variable used in the multiple regressions along with the difference between the two areas.

Variable	**Golf course**	**Urban**	**T-Test**
	Average(±Stdv)	**Average(±Stdv)**	
Other cover (%)	0.0 ± 0.0	0.0 ± 0.0	t = NA, p = NA
Bare cover (%)	0.0 ± 0.0	3.0 ± 5.0	t = 1.96, p = 0.08
Residential vegetation cover (%)	88.0 ± 7.0	43.0 ± 22.0	t = 5.83, p < 0.01
Urban cover (%)	4.0 ± 5.0	12.0 ± 10.0	t = 2.19, p = 0.047
Natural vegetation cover (%)	4.0 ± 5.0	23.0 ± 17.0	t = 3.16, p < 0.01
Water cover (%)	0.0 ± 0.0	9.0 ± 16.0	t = 1.71, p = 0.12
Total average DBH (cm)	23.6 ± 13.9	22.1 ± 16.3	t = 0.21 p = 0.84
No. of indigenous trees	19.7 ± 15.5	51.9 ± 74.0	t = 1.27, p = 0.23
No. of alien trees	12.4 ± 8.1	12.4 ± 9.5	t = 0, p = 1
Total no. of trees	32.1 ± 21.5	64.3 ± 70.9	t = 1.30, p = 0.22
Woody cover (%)	9.5 ± 4.2	10.8 ± 7.1	t = 0.45, p = 0.66
Herb cover (%)	2.6 ± 1.8	5.0 ± 4.34	t = 1.53, p = 0.15
Canopy cover (%)	29.4 ± 5.5	30.0 ± 8.0	t = 0.18, p = 0.86

In addition, there was a greater cover of natural vegetation and indigenous trees in the urban areas compared to the golf courses, with the same average number of alien trees found in each area. The total tree count (alien and indigenous combined) was higher in the urban surrounding areas than on golf courses (Table 4.5). As both golf course and urban settings were situated in the same larger landscape, landscape metrics measured at the landscape scale applied to both. The landscapes were all deemed to have high levels of vegetation (including both natural and non-natural) equating to 3 899 ha of the total 6 224 ha (62.7 % of the total landscape). The cumulative average edge length of the patches within the landscape was 481.8 m, or roughly 446 m per patch, which there was an average of 1 080 patches for each landscape. Of the patches in the landscape, the largest patch area was 5 819.90 ha (more than half of the total landscape) and the average 7.25 ha (Table 4.6).

Table 4.6: The landscape metric values describing the landscape in which both the assessed golf courses and urban areas were situated.

Landscape metric	Average (±Stdv)
Land cover (ha)	3 899.2 ± 1 420.6
Edge length (m)	481 772.0 ± 188 630.1
No. of patches	1 080.0 ± 585.2
Greatest patch area (ha)	3 352.2 ± 1 762.03
Mean patch area (ha)	7.3 ± 9.4

The multiple regression indicated that natural vegetation, closely followed by site, i.e., golf course or urban area, was the most important determinant of bird biodiversity (Table 4.7). This was followed by edge length (statistically significant), number of patches (close to statistically significant), and percentage canopy cover (close to statistically significant). All other variables were not statistically significant.

Table 4.7: Multiple regression assessing the relationships of a range of independent variables with diversity (H) both the golf course and urban data together.

Variable	Estimate	Std. Error	t value	Pr(>|t|)	Signif
(Intercept)	-2.8444	2.518	-1.130	0.322	
Golf course / Urban	1.5272	0.406	3.760	0.020	*
Other	4.46E-08	2.90E-08	1.540	0.198	
Bare	10.9344	7.435	1.471	0.215	
Urban	4.4549	2.197	2.028	0.112	
Natural vegetation	4.1025	1.063	3.858	0.018	*
Water	-3.9561	2.612	-1.514	0.204	
Average DBH	0.053	0.025	2.130	0.100	
No. of indigenous trees	0.0007	0.004	0.199	0.852	
No. of alien trees	0.0033	0.01	0.324	0.762	
Total no, of trees	0.004	0.007	0.572	0.598	
Herb cover (%)	0.0104	0.034	0.309	0.773	
Canopy cover (%)	0.0529	0.022	2.436	0.072	•
Land cover	5.47E-07	2.67E-07	2.046	0.110	
Edge length	4.41E-06	1.50E-06	2.944	0.042	*
No. of patches	-0.0049	0.002	-2.427	0.072	•
Greatest patch area	-5.31E-07	2.54E-07	-2.093	0.104	
Proportion of golf course connected UGI	0.2094	0.244	0.858	0.439	
Signif.codes: <0.05‘*’ >0.05‘.’ >0.1 ‘ ’					
Residual standard error: 2.518 on 4 degrees of freedom Multiple R-squared: 0.958, Adjusted R-squared: 0.800 F-statistic: 6.067 on 15 and 4 DF, p-value: 0.0471					

The fact that the site (golf course or urban area) was the second biggest determinant of biodiversity shows the importance of assessing the factors affecting biodiversity on each site independently. Two individual multiple regressions, one for each area for diversity, richness and evenness, show that none of the eight variables used were significant in determining bird diversity, richness and evenness for either site (Table 4.8.1, 2 and 3). The overall model best described biodiversity in the urban areas ($r^2 = 0.69$) as opposed to the golf courses ($r^2 = 0.39$) (Table 4.8.1).

Table 4.8.1: Multiple regression assessing the relationships of the reduced variables with diversity (H) for the urban areas and golf courses separately.

Variable	Site	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	Urban	1.22	0.62	1.97	0.19
	Golf course	27.66	15.35	1.80	0.32
Other	Urban	NA	NA	NA	NA
	Golf course	-365.68	506.98	-0.72	0.60
Urban	Urban	0.15	1.96	0.08	0.95
	Golf course	-21.91	12.93	-1.69	0.34
Alien count	Urban	0.00	0.01	-0.27	0.82
	Golf course	-0.03	0.01	-2.08	0.29
Herb cover (%)	Urban	0.03	0.02	1.37	0.31
	Golf course	0.13	0.16	0.82	0.56
Canopy cover (%)	Urban	0.02	0.01	1.59	0.25
	Golf course	0.06	0.05	1.11	0.47
Residential vegetation	Urban	-0.13	0.44	-0.29	0.80
	Golf course	-28.57	17.40	-1.64	0.35
Natural vegetation	Urban	1.64	1.07	1.53	0.27
	Golf course	-33.08	22.04	-1.50	0.37
Proportion of golf course connected UGI	Urban	0.12	0.96	0.12	0.92
	Golf course	1.80	1.72	1.05	0.49
Residual standard error: 0.178 on 2 $^{(UR)}$ and 0.1925 on 1 $^{(GC)}$ degrees of freedom, Multiple R-squared: 0.9332 $^{(UR)}$, 0.9319 $^{(GC)}$, Adjusted R-squared: 0.6995 $^{UR)}$, 0.3874 $^{GC)}$, F-statistic: 3.993 on 7 and 2 DF $^{(UR)}$; 1.711on 8 and 1 DF $^{(GC)}$, p-value: 0.2149 $^{(UR)}$; 0.5334 $^{(GC)}$					

Table 4.9.2: Multiple regression assessing the relationships of the reduced variables with evenness (E) for the urban areas and golf courses separately.

Variable	**Site**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	Urban	0.46	0.05	9.20	0.01
	Golf course	5.86	2.15	2.72	0.22
Other	Urban	NA	NA	NA	NA
	Golf course	-67.09	71.06	-0.94	0.52
Urban	Urban	1.63	0.16	10.29	0.01
	Golf course	-4.21	1.81	-2.33	0.26
Alien count	Urban	0.01	0.00	9.87	0.01
	Golf course	-0.01	0.00	-3.83	0.16
Herb cover (%)	Urban	0.00	0.00	2.10	0.17
	Golf course	0.01	0.02	0.66	0.63
Canopy cover (%)	Urban	0.00	0.00	2.19	0.16
	Golf course	0.01	0.01	1.01	0.50
Residential vegetation	Urban	0.00	0.00	2.19	0.16
	Golf course	-5.69	2.44	-2.33	0.26
Natural vegetation	Urban	1.16	0.09	13.37	0.01
	Golf course	-6.82	3.09	-2.21	0.27
Proportion of golf course connected UGI	Urban	-0.68	0.08	-8.68	0.01
	Golf course	0.45	0.24	1.89	0.31
Residual standard error: 0.01441 on 2 (UR) and 0.02698 on 1 (GC) degrees of freedom,					
Multiple R-squared: 0.9957 (UR), 0.9762 (GC),					
Adjusted R-squared: 0.9806 UR), 0.7861 (GC),					
F-statistic: 66.08 on 7 and 2 DF (UR); 5.135 on 8 and 1 DF (GC) ,					
p-value: 0.01499 (UR); 0.3293 (GC)					

Table 4.10.3: Multiple regression assessing the relationships of the reduced variables with richness (R) for the urban areas and golf courses separately.

Variable	Site	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	Urban	18.03	18.90	0.95	0.44
	Golf course	366.19	322.16	1.14	0.46
Other	Urban	NA	NA	NA	NA
	Golf course	-6064.01	10639.60	-0.57	0.67
Urban	Urban	-116.99	59.56	-1.96	0.19
	Golf course	-323.61	271.37	-1.19	0.44
Alien count	Urban	-0.69	0.33	-2.11	0.17
	Golf course	-0.12	0.26	-0.46	0.73
Herb cover (%)	Urban	0.33	0.69	0.48	0.68
	Golf course	3.80	3.27	1.16	0.45
Canopy cover (%)	Urban	0.28	0.31	0.90	0.46
	Golf course	1.59	1.10	1.44	0.39
Residential vegetation	Urban	-4.39	13.33	-0.33	0.77
	Golf course	-406.71	365.16	-1.11	0.47
Natural vegetation	Urban	-47.45	32.65	-1.45	0.28
	Golf course	-406.71	365.16	-1.11	0.47
Proportion of golf course connected UGI	Urban	52.14	29.34	1.78	0.22
	Golf course	-406.71	365.16	-1.11	0.47
Residual standard error: 5.418 on 2 $^{(UR)}$ and 4.04 on 1 $^{(GC)}$ degrees of freedom,					
Multiple R-squared: 0.7293 $^{(UR)}$, 0.8854 $^{(GC)}$,					
Adjusted R-squared:-0.2182 $^{UR)}$, -0.03134 $^{(GC)}$,					
F-statistic: 0.7697 on 7 and 2 DF $^{(UR)}$; 0.9658 on 8 and 1 DF $^{(GC)}$,					
p-value: 0.6688 $^{(UR)}$; 0.6613 $^{(GC)}$					

4.3.4 Site classification

The golf courses analysed spanned a range of urban or vegetation densities. The use of a cluster analysis grouped the golf courses based to the measured variables at each course along with vegetated land cover of the landscape in which they were found. Additionally, the average monthly income per suburb in which these courses were situated was considered. The table derived from the cluster analysis indicates this spread of golf courses across densely vegetated areas, and non/low densely vegetated areas (Table 4.9).

Table 4.11: Differences in variables between the two clusters / types of golf courses.

Variable	**Cluster 1**	**Cluster 2**
	Average (± Stdv)	**Average (± Stdv)**
Diversity (h)	2.6 ± 0.3	2.5 ± 0.3
Evenness (e)	0.7 ± 0.1	0.7 ± 0.1
Richness (r)	32.0 ± 3.8	30.7 ± 5.0
Other cover (%)	0.0 ± 0.0	0.0 ± 0.0
Bare cover (%)	0.0 ± 0.0	0.0 ± 0.0
Residential vegetation cover (%)	87.1 ± 9.5	90.0 ± 0.0
Urban cover (%)	4.3 ± 5.3	3.3 ± 5.8
Natural vegetation cover (%)	5.7 ± 5.3	0.0 ± 0.0
Water cover (%)	0.0 ± 0.0	0.0 ± 0.0
Total average DBH (cm)	15.7 ± 3.8	41.9 ± 14.2
Indigenous count	25.6 ± 16.3	6.0 ± 1.0
Alien count	13.3 ± 10.2	10.3 ± 2.1
Tree count	38.9 ± 24.3	16.3 ± 3.1
Water cover (%)	11.5 ± 3.8	4.8 ± 0.5
Herb cover (%)	2.7 ± 2.0	2.3 ± 2.1
Canopy cover (%)	28.5 ± 6.5	31.5 ± 3.9
Land cover (ha)	4 753.9 ± 608.8	1 904.7 ± 674.6
Edge length (km)	396.1 ± 147.5	681.6 ± 164.4
No. of patches	724.6 ±280.3	1 909.3 ± 52.9
Greatest patch area (ha)	4418.8 ± 789.9	863.5 ± 616.2
Mean patch area (ha)	9.9 ± 10.9	1.0 ± 0.3
Income (Rand)	23 910.0 ± 10 818.3	18 912.0 ± 3 037.9
Proportion of golf course connected UGI	0.6 ± 0.2	0.5 ± 0.2

Cluster 1 grouped golf courses that have greater natural vegetation cover, indigenous count, total tree count, woody cover, herb cover, land cover, greatest patch area and mean patch together (Figure 4.4 and Table 4.9) This cluster also had fewer patches and shorter edge lengths than Cluster 2, indicating a comparatively more natural, and less built-up landscape. The variables making up this cluster indicated that it consisted of the more natural courses, whilst Cluster 2 comprised more urban-situated courses. Moreover, Cluster 1, or the natural golf courses, had a higher bird diversity, evenness and richness index, whilst also being situated in wealthier areas. However, there is no significant relationship between bird diversity and wealth gradient (linear model, $p = 0.16$, $r = 0.11$) (Figure 4.5). However, there is a highly significant relationship between the wealth gradient of the suburbs the golf courses are situated in and the size of the golf courses ($p < 0.001$, $r = 0.58$).

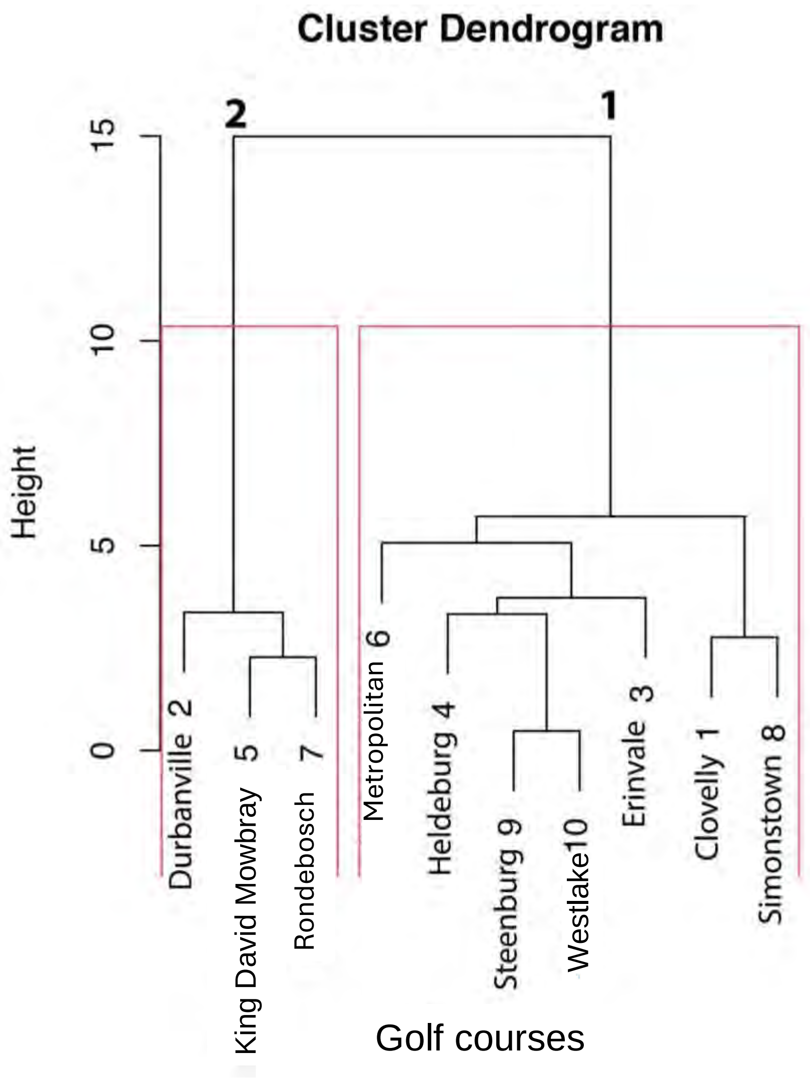

Figure 4.4: Cluster analysis of golf courses determined by the measured variables outlined in Table 4.9 with the inclusion of Diversity, Richness, Evenness as well as the proportion the golf course perimeter connected to other UGI.

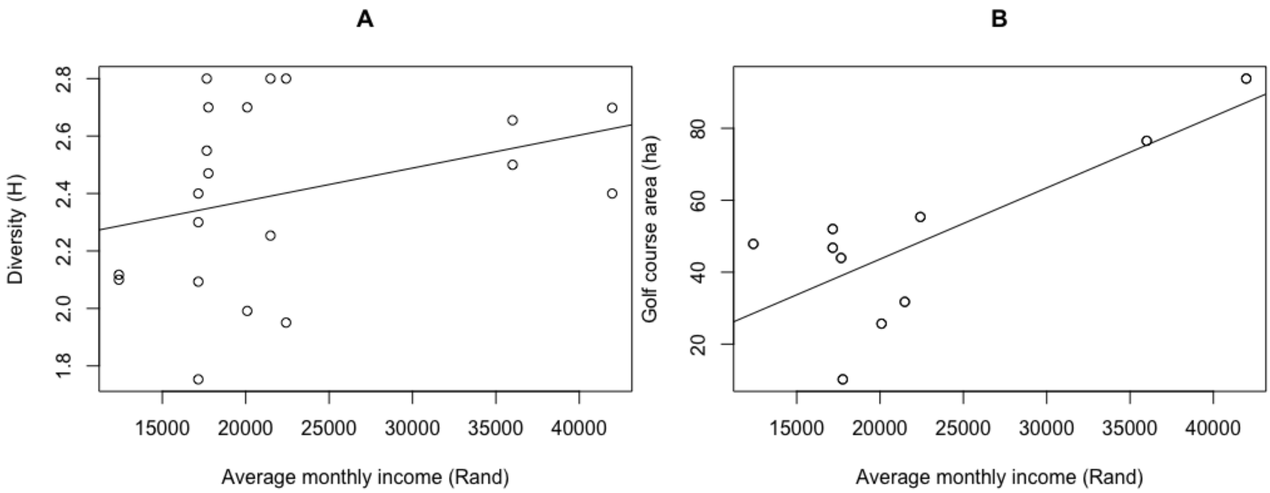

Figure 4.5: Shannon Diversity Index (H) (A) and area of Golf Course (B) with the increase in average income for the area/suburb in which the golf course is situated.

4.4 Discussion

4.4.1 Biodiversity of golf courses

This study compared biodiversity on golf courses, which comprise mostly of green areas, compared to surrounding areas that have a high proportion of grey land-use. Results of this study indicate that there was a higher bird richness on the golf courses compared to the urban areas, with 98 species identified on the golf courses and 78 in the urban surrounds. Further supporting this was the greater number of individuals; with 5 064 on golf courses and 4 128 in urban areas. Additionally, a total of 41 species were sighted only on golf courses, while only 16 were seen exclusively in the surrounding urban areas. These results indicate that golf courses may provide habitat for a greater diversity and abundance of bird species compared to urban areas. This finding corresponds with the review by Colding and Folke (2009), who found that 64 % of papers reported that golf courses have a positive ecological benefit in comparison to other land uses (where green spaces tend to be present). Similar patterns were also noted for the richness of a variety of taxa whilst also applying to multiple measures biodiversity of bird and insects (Colding and Folke, 2009).

The results of this study indicate that golf courses in the City of Cape Town support significant bird biodiversity, as indicated by the higher diversity, richness, and evenness of bird species compared to the surrounding urban areas. The Shannon-Wiener diversity index for the golf courses was significantly higher than that of the urban areas, with all golf courses, except for three (Erinvale, Steenberg, Westlake), having greater diversity. The multiple regression indicated the strongest significant influential factor/s for this difference was natural vegetation. This is an expected outcome as more natural settings are likely to support greater biodiversity than urban landscapes. The second most statistically significant factor was the site (i.e. golf course or urban areas), where golf courses appear to support greater biodiversity than urban areas, followed by edge length. These results indicate that both the composition of the golf course, but also the landscape in which it is situated, play an important role in determining bird biodiversity, suggesting that landscape context is crucial. Other factors that showed a strong though not statistically relationship with biodiversity were canopy cover and edge length. All other variables did not demonstrate significant relationships with biodiversity. These results are interpreted alongside an acknowledgement that variables with larger scales may have coefficients that are numerically larger, making it difficult to directly compare the importance of different predictors. Additionally, variables with larger scales may be more influenced by outliers compared to variables with smaller scales, and can also exacerbate collinearity.

The findings of this multiple regression are supported by Tanner and Gange (2005) who find significantly higher levels of avifaunal diversity on golf courses compared to surrounding farmland, which again would suggest that there would be even greater difference when compared to urban areas. Sorace and Visentin's (2007) comparison of bird biodiversity on golf courses and surrounding urban agricultural areas also indicates that, in most cases, biodiversity was higher on golf courses than in surrounding areas. Additionally, Threlfall *et al.* (2016) indicate similar distributions in terms of avifaunal and bat assemblages, where their sites also spanned a range of different areas.

This study therefore contributes and adds nuance to an existing body of literature contradicting the notion that golf courses are merely 'green deserts'. Whilst these findings relate specifically to avifaunal diversity, they suggest greater environmental health as well as lower ecological and environmental change on the golf courses compared to the surrounding urban areas. Here, Mekonen's (2017) conceptualisation of avian species as bioindicators is relevant, as avian species have been used to assess and indicate a range of environmental concerns, such as, contamination from pollutants, pesticides and heavy metals. They have also been used as surrogates for other taxa as well as to the condition of environments and their responses to disturbances and processes (Santangeli and Girardello, 2021).

As golf courses have higher avifaunal biodiversity, a variety of variables were also assessed to describe this. Tanner and Gange (2005), who also found higher biodiversity, report a significantly positive relationship between tree diversity and avifaunal diversity. This is in support of this thesis, as natural vegetation (significant) closely followed by canopy cover (close to statistically significant) indicated strong and positive relationships with biodiversity.

Additionally, when considering these variables on the golf and urban areas individually, none of the measured variables (vegetation, connectivity and land use) had a significant relationship with the bird diversity. This result is unexpected, as it is widely understood that these variables affect diversity and avifaunal diversity, hence their inclusion in the study (Aida *et al.,* 2016; Berg, 1997; Dures and Cumming 2010; Mellink *et al.,* 2017). For instance, vertical structures (trees) are considered to have a positive relationship with avifaunal diversity as they provide secure places for perching, feeding and nesting (Culbert *et al.,* 2013; Lee and Rotenberry, 2005). Woody plant species diversity and avian diversity and richness are also considered to have a positive relationship (Choudaj and Wankhade, 2023). Furthermore, significant relationships between type of plant species (i.e. native and/or alien) and avian species have been widely recorded (Choudaj and Wankhade, 2023; Flanders *et al.,* 2006; French *et al.,* 2005).

These results align are unsurprising as it is widely cited that certain compositional factors (i.e., variables that are present within each site) and landscape connectivity factors positively enhance ecosystem functioning (Bailey, 2007; Culbert *et al.,* 2013; Tischendorf and Fahrig, 2000). However, much of the present literature that addresses golf course biodiversity neglects connectivity. Studies neglecting connectivity factors carry the risk that findings may be less robust or fail to adequately conceptualise the impact of golf courses within the landscapes in which they are situated.

Regarding the composition of the sites, both were comprised of attributes that contribute positively towards avifaunal diversity (presence of trees, water bodies, natural vegetation) as well as those variables that are considered to have detrimental effects (grey infrastructure) (Concepción *et al.,* 2015; Culbert *et al.,* 2013). Culbert *et al.* (2013) note the positive relationship between nesting availability and avian species richness, whilst Concepción *et al.* (2015) note how urbanisation drives the change replacing the present specialists to generalists, resulting species homogenisation.

There was an increase in diversity with the decrease in the number of patches within the broader landscape that encompass the golf courses (or increased connectivity). This raises the issue of connectivity lacking in many studies, (Sorace and Visentin, 2007; Tanner and Gange, 2005 and Yasuda and Koike, 2006), as it is apparent that the number of patches plays an important role in the structural and compositional differences in the urban and golf course settings. To further understand the factors that affect biodiversity in each area independently, multiple regressions were conducted for each area. The results of these analyses showed that none of the eight variables were significant in determining the bird biodiversity of each area. The same was true for richness and evenness. However, there were some significances noted for evenness within the urban area only. This was surprising as there was both an abundance and lack of trees, difference in size, shape and class (native or alien) across golf courses and urban areas, which one would expect would significantly alter avifaunal diversity (Culbert *et al.,* 2013; Shackleton, 2016). The same is true for the presence of urban infrastructure, and total or mean patch area, which again as seen with the changes in presents of tree qualities, also had no effects of biodiversity. However, it is possible that the small sample size limited the power of the analysis.

The results of this study indicate that the presence of water bodies on golf courses are not an important factor in promoting bird biodiversity. This contrasts to Morelli *et al.*'s (2021) findings, where water bodies attracted waterfowl species such as ducks and geese and wading birds such as herons, egrets and ibises. While all golf courses included human-made, freshwater water bodies as part of their composition, that was not so for the urban areas. While this may skew the results, water bodies, as a course hazard, are common in most golf courses. For example, in the USA, water makes up seven percent of an 18-hole course (Lyman *et al.,* 2007). This proportion is very similar to the ten sampled courses in Cape Town (6.5 %) although not all were 18-hole courses. While the presence of water bodies on the golf courses was not found to be statistically significant in relation to avifaunal diversity, removing aquatic species from the data set revealed that the presence of water bodies on the golf courses did reduce bird biodiversity, but insignificantly.

Although all analysed golf courses were located within the Cape Town municipal boundaries and classified as urban golf courses, they spanned a range of urban or vegetated densities at the landscape scale. The average monthly income of the suburbs in which the courses were located was also considered. The cluster analysis revealed that the golf courses were spread across densely vegetated and non/low densely vegetated areas creating the two groups: 'more' and 'less natural'. As expected, the courses in Cluster 1, the more natural group, had enhanced natural variables in comparison to Cluster 2, the less natural group. However, despite coinciding with the trends noted within each group, the noted bird diversity does contradict some previous studies and patterns in the literature. Colding and Folke (2009) note the increase in golf course ecological values in comparison to land with high anthropogenic impacts. Similarly, Hodkins and Warner (2005) suggest the ability of golf courses to act as wildlife refuges in inhospitable urban landscapes. Sorace and Visentin (2007) have similar findings. Of the courses sampled by them, one was situated in an urban setting, one in an intensive agricultural area, and the last in an agriculture area characterised by meadows, small woods, bushes and some country houses and gardens (Sorace and Visentin, 2007). With the biggest differences in diversity between the golf course and surrounding areas seen in the urban and intensive agriculture areas, the impacts of an urban gradient on diversity seem clear. Insights from the literature indicate that the lack of connectivity turns these isolated golf courses into important areas or hotspots for biodiversity. This may be true with regards to creating hotspots of biodiversity, but also results in the present communities being vulnerable to change (Lampila *et al.,* 2005; Montero *et al.,* 2021). Sorace and Visentin's (2007) findings in fact showed little to no differences between the courses (themselves) when assessed along this gradient.

Moreover, the more natural courses had greater bird diversity, richness and evenness. This supports the multiple regression where natural vegetation had the strongest relationship with bird biodiversity. In contrast, the 'less natural' courses had lower diversity, evenness, and richness and were located in less wealthy areas. These findings are in line with the literature, where it has been noted that biodiversity increases with enhanced connectivity as well as the decrease in connectivity in urban settings, creating a non-linear curve. This is largely due to highly connected landscapes providing a large quantity of area for species to thrive in (Bailey, 2007). However, isolated patches within an urban matrix area also considered to act as an island for diversity, creating an isolated hotspot or place for refuge for fauna and flora (Yasuda and Koike, 2006; for more information on this idea, consult MacArthur and Wilson's [2021] island biogeographical theory). Furthermore, Callaghan *et al.* (2019), also made specific reference to this non-linear relationship bird diversity and vegetation follow, where the mix of land uses within moderately disturbed urban settings (i.e. residential areas) where both green and grey infrastructure are present is deemed to be optimal for birds. This is largely due to greater provision of resources for birds to thrive off (Callaghan *et al.,* 2019).

There was no significant relationship between bird diversity and the wealth of the suburbs in which the golf course were situated. This is contradictory to the frequently reported luxury effect whereby more affluent neighbourhoods boast greater diversity and green cover (Leong *et al.,* 2018; Venter *et al.,* 2020). Howes and Reynolds (2021) made refence to this luxury effect, noting its applicability across both faunal and floral species. This is supported by McCoy *et al.* (2022) noting greater tree diversity and abundance in wealthier areas, with Leong *et al.* (2018) noting the applicability of this effect on both bird and bat species. However Anderson *et al.* (2021) indicate that not all ideas, including the luxury effect, stemming from the Global North are transferable. For example, Cilliers *et al.* (2011) indicate that some households with a lower socioeconomic status on the urban periphery in the Global South house greater number of indigenous plant. Moreover, Howes and Reynolds (2021) also noted an absence of the luxury effect with bird species in Johannesburg, South Africa. This may be the case here with regards to bird diversity, however is not the case regarding the present UGI. Venter *et al.* (2020) noted a strong luxury and legacy effect in South Africa, where Cape Town and Johannesburg, portrayed the strongest relationships. Further research is needed to fully understand the relationship between golf courses and local diversity, wealth, and land cover.

4.4.2 Urban adaptors

The results showed that the most common bird species on the golf courses and adjacent urban areas differed significantly. The Egyptian Goose was the most prominent species on the golf courses, with 951 individuals recorded across the ten courses. According to respondents in a study base on one of the sampled courses (Steenberg Golf Estate) the high count of Egyptian Geese on the golf course is a problem for the management, because the geese produce large quantities of excrement on and off the course, while also harassing other bird species (Little, 2020). Golfers in the same study suggested that the goose population should be reduced by more than 50 %, which was supported by the non-golfing population of the estate (Little, 2020).

In contrast, there were only 73 Egyptian Geese recorded in the urban surrounds. The most common species in the urban areas, the Common Starling, had a count of 863 individuals. As the Common Starling has a high reliance on human resources and infrastructure in the form of food (food waste) and perching and nesting opportunities, it is classified as an urban exploiter (Isaksson, 2018).

Despite these two species having similar total counts, the golf courses had far fewer urban adaptor species compared to the urban areas, with a total of 1 476 individuals on the golf courses and 2 284 in the urban areas. These figures equate to roughly 30% of all species on the golf courses and over 55% in the urban areas. This suggests that the species found on the golf courses are of greater ecological importance as it houses a greater proportion of urban avoiders encompassing specialist and native species than the urban areas.

A total of 20 urban adaptor species were recorded, with 19 in urban areas and 18 on golf courses. The Muscovy Duck was the only urban adaptor species seen on the golf courses and not in the urban areas, while the Barn Swallow and Little Swift were the only urban adaptors found in the urban areas and not on the golf courses. These results suggest that urban adaptor species may have stronger presence in urban areas compared to golf courses.

Of the two most common species that were also urban adaptors, found in both sites, only the Common Starling is classified as an introduced species. All four of the introduced species were found on the golf courses and three in the urban areas, with no statistical difference noted.

4.5 Conclusion

Results of this study suggest that golf courses in the City of Cape Town support significant bird diversity and a greater variety of species than neighbouring land uses. A total of 114 species out of 303 present in the Cape Peninsula were identified on golf courses, with a higher diversity, richness, and evenness of species on golf courses compared to the surrounding urban areas.

These findings align with existing literature that indicates higher levels of avifaunal diversity on golf courses compared to surrounding areas. The results of this study complicate the notion that golf courses are 'green deserts' and ecological disasters, and places greater focus on urban areas (which remains relatively neglected in the literature). It was found that enhanced connectivity aided avifaunal diversity at the landscape level, having positive effects on the noted bird diversity on and off the golf courses. With the same connectivity metrics applied to both sites, it is the habitat variables deemed to be the reason for the difference in the noted biodiversity. There were however limited results describing differences in diversity noted at the site when assessed individually. This is interesting, as structurally, the two areas are vastly different and the habitat variables in the grouped multiple regression portrayed significances. With these structural differences and the significant difference noted in the present diversity, it was expected that the measured variables would account for this. With both sites having variables that both aid and reduce biodiversity, this may be the reason for the insignificant finding. This will need to be further addressed as to aid and support the management and techniques employed by golf courses manages and urban planners as to aid and enhance the diversity found within these two areas. This is also an area to addressed further in the literature, unpacking and refining the cause for these findings.

Although golf courses support significant avifaunal diversity in comparison to their urban surroundings, indicating that they provide some ecological services, they still need to be viewed with caution. This is largely due to their water consumption, fertilizer use, 'monoculture' in the form of turf grass, and land transformation. Findings of this study suggest that there are a range of variables that determine bird diversity and that both habitat and landscape variables are important. Whilst this chapter highlights the importance of connectivity and the landscape context in determining bird biodiversity, habitat variables appear to be the reason for the difference in biodiversity between golf courses and surrounding urban landscapes.

Chapter 5: Conclusion

5.1 Synthesis of findings

This study sought to assess the potential of urban golf courses to foster avifaunal diversity, as well as address their connectivity to other forms of urban green infrastructure (UGI). Five key questions guided this analysis: 1) To what extent are golf courses connected to other UGI? 2) How and to what extent do golf courses affect the patterns and process of the greater urban landscape? 3) How does the connectivity of golf courses to other local UGI affect the avifaunal diversity of the golf course? 4) How and to what extent does the avifaunal diversity of golf courses differ from that of the surrounding urban landscape? Lastly, 5) Is there any relationship between the extent and composition of vegetation and bird diversity?

Urban golf courses are situated in areas of significant land transformation and may provide unique functions and roles in transformed landscapes, in a similar fashion to other UGI (Petrosilo *et al.,* 2019). Of interest for this study is the role urban golf courses may play in supporting biodiversity, using avifauna as an indicator group, in comparison to the directly neighbouring urban environment. Additionally, this study took into consideration and highlighted the importance of connectivity and the landscape context when doing any form of biological assessment. Chapter 3 focused on the connectivity of golf courses to their surrounding landscapes. This analysis indicated that all golf courses are connected to some extent to other UGI whilst minimally enhancing the landscapes at hand. Chapter 4 focused on the contribution of the measured connectivity and landscape outline in Chapter 3 to biodiversity in the form an assessment of avifauna.

5.1.1 To what extent are golf courses connected to other UGI?

Within the three cities, each golf course was analysed with regards to, if, and to what extent it was connected to other UGI. All golf courses were at least to some extent connected to other forms of UGI. This finding is important as connectivity and landscape context are widely acknowledged as crucial in facilitating and supporting a range of taxa (Bailey, 2007;

Tischendorf and Fahrig, 2000). Despite this significance, very few of previous studies considered landscape context in this way.

This result stresses the point that urban golf courses are not isolated habitats or patches. Rather, they are connected to other UGI, potentially providing valuable resources such as greater feeding, perching and nesting opportunities that may aid and support biodiversity. Whilst the quantity of UGI varied between landscape and cities, it is important to note that UGI was connected to all golf courses, increasing the size and connectivity of the courses. Moreover, there were various types of UGI connected to the golf courses along with grey infrastructure, enhancing the heterogeneity of the habitat. This created habitats of varying resources including both natural and anthropogenetic factors. Notably for bird species, these resources would be that of typical naturally occurring foods as well as anthropogenic ones in the form of bird feeders and discarded food waste. The addition of anthropogenetic factors along with a greater amount of natural food resources would attract a wider range of species. Callaghan *et al.* (2019) note this, suggesting birds follow a non-linear relationship with the urban gradient, where diversity peaks at moderately disturbed sites. Former studies, of which Sorace and Visentin, (2007) were one, also highlighted the importance of golf courses in urban settings but did not quantify the varying amounts of urban green and grey infrastructure present, the components of the mixed habitat to which Callaghan *et al.* (2019) refer. This dissertation therefore serves as a starting point for the incorporation of connectivity into ecological assessment, providing a more nuanced picture of the ecological impact of urban golf courses.

5.1.2 How and to what extent do golf courses affect the patterns and process of the greater urban landscape?

Assuming urban land uses would occupy the spaces in which golf courses are currently situated, there is a possibility that golf courses might not only be connected to the landscape but may also *enhance* the overall connectivity of the landscape. Chapter 3 therefore also considered this aspect. The analysis of golf courses' direct contribution to the landscape connectivity failed to conclusively illustrate that they enhance overall connectivity. However, the findings are likely related to the scale and size of the landscape addressed in relation to the scale and size of golf courses as well as the high abundance of vegetation cover present in the cities analysed. In other words, golf courses made up a small proportion of the UGI present in Cape Town, Johannesburg, and Gqeberha.

For this reason, the chapters of this dissertation should also not be considered in isolation. Chapter 4, which involves a comparison of bird biodiversity on golf courses and surrounding urban areas, enhances one's understanding of the findings of Chapter 3. When the findings of Chapter 3 and 4 are considered together, golf courses' contribution to functional connectivity and biodiversity support becomes clearer. Despite the insignificant findings illustrating their ability to enhance connectivity, the connection between golf courses and other UGI allows additional perching, feeding, breeding and nesting opportunities, all of which likely enhance avifaunal diversity, a topic neglected from previous similar studies (Callaghan *et al.,* 2019).

5.1.3 How does the connectivity of golf courses to other local UGI affect the avifaunal diversity of the golf course?

To address potential pitfalls of previous studies, this study aimed to illustrate what already is already widely acknowledged, the importance of connectivity for biodiversity (Bailey, 2007; Baguette and Van Dyck, 2007). Although Chapter 4 did not have an explicit focus on structural connectivity, it built on the previous chapter that considered the extent to which golf courses were connected to other forms of UGI. Taken together, these chapters indicate that golf courses, connected to surrounding UGI, enhance and support the present bird biodiversity in urban settings.

Despite Chapter 3 illustrating insignificant findings regarding measures of structural connectivity, there was still a significantly greater amount of avifaunal diversity found on the golf courses than the corresponding urban areas in the sampled 10 courses in Cape Town (Chapter 4). There is however a risk that this enhanced biodiversity on golf courses could be an 'ecological trap' as biodiversity is 'tricked' into thinking these areas are of ecological value (Saarikivi, 2016). However, where these ecological traps do exist, they may still be valuable as areas species are able to move through. In cases where golf courses are well-established and utilised by various species, it seems less suitable to label them as ecological traps, but rather as areas aiding functional connectivity. This is the case for many golf courses in Cape Town in particular, whose placement in the city is well-established (average age of golf courses 79 ± 39 years old), and some of which date back to the early 1900s. Moreover, these spaces are also connected to other UGI, of which residential vegetation found in gardens and backyards formed part, suggesting birds selected golf courses out of choice, rather than as an ecological trap. Moreover, whilst applicable to other taxa, fences and walls do not limit the movement of birds, further supporting this above point.

As birds were used as the taxa of choice, because these highly mobile species do not solely rely on structural connectivity to move, but rather need a variety of patches and habitats to move between, these results were somewhat expected. However, cognisant of structural connectivity, it is still a vital measure to incorporate in studies of this sort as other contexts will differ, where structural connectivity may be of importance. Furthermore, for other taxa that require connected habitats to move, or are less mobile than birds, this measure cannot be ignored. Although some of the literature noted the context in which golf courses were situated and the importance thereof, measures of connectivity, structural and functional were largely absent.

5.1.4 How and to what extent does the avifaunal diversity of golf courses differ from that of the surrounding urban landscape?

The extent to which golf courses were connected to the wider landscape, especially other UGI, informed the more refined investigation of biodiversity in Chapter 4. This chapter narrowed in on one of the three cities in which the urban context was considered, Cape Town. It assessed avifaunal diversity of golf courses in relation to surrounding urban areas. Ten of the 18 courses in Cape Town were analysed. There was significantly higher bird diversity on golf courses in comparison to the surrounding urban areas, illustrating the importance of golf courses within an urban environment. In addition, the birds recorded were also consider of greater ecological importance on the golf courses, due to the lower recordings of urban exploiters noted on golf courses compared to the urban settings. These results illustrate the ways in which golf courses may contribute to biodiversity in disturbed settings specifically.

These findings corroborate existing literature on this topic (Tanner and Gange, 2005; Sorace and Viscentin, 2007), although the corpus of literature has less focus on urban landscapes. Chapter 4 therefore serves to grow and contribute to gaps in a burgeoning literature on urban golf courses. Novelty of the research stems from the study site chosen in a context where most literature focuses on urban settings in the Global North, and the analysis of golf courses in relation to the wider landscape, as opposed to an isolated land use seen more often in previous studies.

5.1.5 Is there any relationship between the extent and composition of vegetation and bird diversity?

The level of biodiversity noted was critically analysed, as well as its relationship with a range of variables. As noted above, there were significant relationships between bird diversity and connectivity as well as some vegetation. As the same measures of connectivity were applied to both sites, it was considered that the habitat specific variables were the cause in difference between the golf courses and urban areas. Whilst that may have been true when all the sites (golf course and urban areas) were addressed together, it was not the case when addressed separately. This was not expected as the variables measured are widely aligned to have significant relationship with bird diversity (Culbert *et al.,* 2013; Dong *et al.,* 2022; Mellink *et al.,* 2017; Sánchez-Sotomayor et *al.,* 2023).

A potential reason for the lack of conclusive findings could be that there were only 10 sites addressed in each area, suggesting that a larger sample set be used in future work. Furthermore, the variables addressed were limited to their type (native or alien) and the size and quantity of vegetation present. In future studies, a greater range of vegetation variables that address and speak to the different bird feed guilds, for instance, should be applied, addressing factors such as nectar and pollen availability or presence and/or production of seeds. There is therefore room for other studies to assess the extent or power of vegetation to influence bird diversity in relation to other factors, including connectivity.

5.2 Implications of the findings and recommendations for future research

This thesis highlighted the importance of using a range of variables influencing diversity when undergoing ecological assessments. There is substantive evidence in the results of this dissertation and from previous authors (Bailey, 2007; Callaghan *et al.,* 2019; Morelli *et al.,* 2018; Tischendorf and Fahrig, 2000) that landscape context matters when assessing patterns of diversity. This effect on biodiversity is complex; it may not follow a linear trend but rather a non-linear one due to both the presence of natural and non-natural features and land uses.

Further research is necessary to better understand how golf courses can and should be managed to support bird and other biodiversity in conjunction with other UGI. In the Global South context, which is complex and dynamic in nature, this information is vital, as these dynamic and changing landscapes may provide opportunities to incorporate and preserve existing natural vegetation and UGI in a way that may contribute to ecological and socioeconomic sustainability. The following points highlight key areas for future research:

- Chapter 4 considered only 10 golf courses situated in proximity. A more comprehensive understanding would require similar studies conducted on a larger scale, perhaps making use of GIS and open-source data catalogues such as eBird data or iNatualist. These studies come with their own challenges but are important in developing this body of understanding.
- Chapter 4 highlighted that golf course are valuable areas for biodiversity within urban settings. However, in the Global South, characterised by significant socio-economic challenges and disparities, these findings potentially undermine other important topics and contextual issues. Issues such as housing, accessing natural resources and a sense of place, all come to mind when considering golf courses, which are predominantly privately-owned spaces accessible only to affluent members of society. In the South, many people rely on public open areas and UGI for a range of services – access to these services is more limited on golf courses due to their exclusivity (Shackleton, 2021). Moreover, these spaces that may boast an array of diversity benefit only a handful of people. The complex context in which the findings of this research were generated therefore needs to be seen as a part of the larger holistic picture, accounting for the nature of social and demographic landscapes. Future research unpacking the implications of these findings regarding the socio-economic context of South Africa (and similar Global South countries) is of utmost importance.
- This thesis assessed golf courses in urban areas characterised by high land transformation, dominated by grey infrastructure. Whilst the cities chosen spanned and addressed a diverse range of South African landscapes, all have high levels of greenery and vegetation. Using World Health Organisation (Morar, *et al.,* 2104; World Health Organisation, 2010) recommendations on minimum standards for area of public green space in cities, the quantity of vegetation at large recorded in these South African Landscapes were well above the minimum average area per person. Furthermore, due

to the context in which this study is situated, the periphery of the cities can be classified as rural-urban areas with high levels of greenery. Cape Town is further unique with a large national park situated within it, and Johannesburg as well, characterised by having one the world's largest urban forests (Wende, 2010). This potentially undermines the typical 'urban' context of other cities, indicating the need for studies to be conducted in other urban contexts.

5.3 Final reflections

Many people have illustrated the importance of connectivity for a range of taxa and their diversity. However, this dimension has been excluded from literature addressing biodiversity of golf courses in a variety of contexts. This thesis aimed to illustrate the importance of connectivity in all studies of golf courses. It highlighted the extent to which golf courses were connected to the overall urban landscapes of study sites and explored the impact of golf courses in Cape Town on bird biodiversity, indicating greater biodiversity on golf courses in comparison to surrounding areas. Furthermore, not only was the diversity greater on the golf courses, the connectivity measured also appeared to make an impactful difference to the present diversity noted. In the process, the birds recorded were also considered to be of greater ecological importance on the golf courses, due to the lower recordings of urban exploiters noted in golf courses compared to urban settings.

This study was conducted with the aim to add nuance to the literature about the ecological impact of golf courses in urban settings specifically, with the hope to encourage future research allowing one to better understand the complexity that is apparent. This dissertation is a starting point in a growing understanding of the areas that may contribute to UGI, and therefore support biodiversity and other ecosystem functions in urbanised settings. In various Global South contexts, experiencing rapid urbanisation alongside environmental concerns, such as land use change and biodiversity loss, research of this nature is pertinent and pressing.

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Appendix

Table 1: Classification Scheme: List of the SANLC 2020 land classes indicating the re-classed land use classes. Natural Vegetation = 1 - 13,42- 44,46; Water = 14-19, 22-24, 73; Other = 20 - 21, 70 - 72; Bare = 25 - 31, 45, 50, 54 - 56, 60, 64; Agriculture = 32 - 41; Residential/Urban/Recreational Vegetation = 47 - 49, 51 - 53, 57 - 59, 61 - 63; and Urban = 65 – 68

Class No.	Class	Class No.	Class	Class No.	Class
1	Contiguous (indigenous) Forest (*combined* very high, high, medium)	20	Artificial Sewage Ponds	40	Commercial Annuals Crops Rain-Fed / Dryland / Non-Irrigated
2	Contiguous Low Forest & Thicket (*combined classes*)	21	Artificial Flooded Mine Pits	41	Subsistence / Small-Scale Annual Crops
3	Dense Forest & Woodland (35 - 75% cc)	70	Mines: Extraction Sites: Salt Mines	47	Residential Formal (Tree)
4	Open Woodland (10 - 35% cc)	71	Mines: Waste (Tailings) & Resource Dumps	48	Residential Formal (Bush)
5	Contiguous & Dense Planted Forest (*combined classes*)	72	Land-fills	49	Residential Formal (low veg / grass)
6	Open & Sparse Planted Forest	25	Natural Rock Surfaces	51	Residential Informal (Tree)
7	Temporary Unplanted Forest	26	Dry Pans	52	Residential Informal (Bush)
8	Low Shrubland (other regions)	27	Eroded Lands	53	Residential Informal (low veg / grass)
9	Low Shrubland (Fynbos)	28	Sand Dunes (terrestrial)	57	Smallholdings (Tree)
10	Low Shrubland (Succulent Karoo)	29	Coastal Sand Dunes & Beach Sand	58	Smallholdings (Bush)
11	Low Shrubland (Nama Karoo)	30	Bare Riverbed Material	59	Smallholdings (low veg / grass)
12	Sparsely Wooded Grassland (5 - 10% cc)	31	Other Bare	61	Urban Recreational Fields (Tree)
13	Natural Grassland	45	Fallow Land & Old Fields (Bare)	62	Urban Recreational Fields (Bush)
42	Fallow Land & Old Fields (Trees)	50	Residential Formal (Bare)	63	Urban Recreational Fields (Grass)
43	Fallow Land & Old Fields (Bush)	54	Residential Informal (Bare)	65	Commercial
44	Fallow Land & Old Fields (Grass)	55	Village Scattered (bare only)	66	Industrial
46	Fallow Land & Old Fields (Low Shrub)	56	Village Dense (bare only)	67	Roads & Rail (Major Linear)
14	Natural Rivers	60	Smallholdings (Bare)	68	Mines: Surface Infrastructure
15	Natural Estuaries & Lagoons	64	Urban Recreational Fields (Bare)		
16	Natural Ocean, Coastal	32	Cultivated Commercial Permanent Orchards		
17	Natural Lakes	33	Cultivated Commercial Permanent Vines		
18	Natural Pans (flooded @ obsv time)	34	Cultivated Commercial Sugarcane Pivot Irrigated		
19	Artificial Dams (incl. canals)	35	Commercial Permanent Pineapples		
22	Herbaceous Wetlands (currently mapped)	36	Cultivated Commercial Sugarcane Non-Pivot (all other)		
23	Herbaceous Wetlands (previous mapped extent)	37	Cultivated Emerging Farmer Sugarcane Non-Pivot (all other)		
24	Mangrove Wetlands	38	Commercial Annuals Pivot Irrigated		
73	Fallow Land & Old Fields (wetlands)	39	Commercial Annuals Non-Pivot Irrigated		

Table 2: SANLC classes included and excluded as green areas for maps that both include and exclude recreational areas. The Classification Scheme indicates 1 = green areas and 0 = non-green

Re-Classed Landscape Maps (With/Without recreation areas)	
Map 1 Golf course Landscape including recreational areas (with rec)	Map 2 Golf course Free landscape excluding recreational areas
1 - 19 = 1	1 - 19 = 1
20 - 21 = 0	20 - 21 = 0
22 - 26 = 1	22 - 26 = 1
27 = 0	27 = 0
28 - 30 = 1	28 - 30 = 1
31 = 0	31 = 0
32 - 44 = 1	32 - 44 = 1
45 = 0	45 = 0
46 - 48 = 1	46 - 48 = 1
49 - 50 = 0	49 - 50 = 0
51 - 52 = 1	51 - 52 = 1
53 - 56 = 0	53 - 56 = 0
57 - 58 = 1	57 - 58 = 1
59 - 60 = 0	59 - 72 = 0
61 - 63 = 1	73 = 1
64 - 72 = 0	
73 = 1	

[Note: Classes '61-63' were included and excluded from the two different maps used to describe connectivity with and without recreational areas]

Table 3: List of all recorded species with their guild and location of recording (Golf Course or Urban)

Common Name	Bird Guild	Location	Common Name	Bird Guild	Location
American Pekin	Mixed diet	GC	Ibis, African Sacred	Mixed diet	GC+UR
Apalis, Bar-throated	Insectivores	UR	Ibis, Hadeda	Insectivores	GC+UR
Avocet, Pied	Other	GC+UR	Kestrel, Lesser	Mixed diet	GC
Barbet, Acacia Pied	Mixed diet	UR	Kestrel, Rock	Mixed diet	GC
Batis, Cape	Insectivores	GC	Kingfisher, Pied	Piscivore	GC
Bishop, Yellow	Granivore	GC	Kite, Yellow-billed	Mixed diet	GC+UR
Bokmakierie, Bokmakierie	Insectivores	GC	Lapwing, Blacksmith	Mixed diet	GC+UR
Boschveld Chicken	Mixed diet; Other	GC+UR	Longclaw, Cape	Insectivores	GC
Boubou, Southern	Insectivores	GC+UR	Masked-weaver, Southern	Granivore	GC+UR
Bulbul, Cape	Frugivore	GC+UR	Moorhen, Common	Other	GC
Bunting, Cape	Granivore	UR	Mousebird, Red-faced	Mixed diet	GC+UR
Buzzard, Common (Steppe)	Vertebrate prey	UR	Mousebird, Speckled	Mixed diet	GC+UR
Buzzard, Jackal	Vertebrate prey	GC+UR	Mousebird, White-backed	Mixed diet	GC

Canary, Cape	Granivore	GC+UR	Night-Heron, Black-crowned	Mixed diet	GC
Canary, Yellow	Granivore	GC+UR	Oystercatcher, African Black	Other	GC+UR
Chaffinch, Common	Granivore	GC	Paradise-flycatcher, African	Insectivores	GC+UR
Cisticola, Cloud	Insectivores	GC	Peafowl, Indian	Mixed diet	GC+UR
Cisticola, Levaillant's	Insectivores	GC	Penguin, African	Piscivore	GC+UR
Coot, Red-knobbed	Other	GC+UR	Petronia, Yellow-throated	Granivore	GC
Cormorant, Cape	Piscivore	GC+UR	Pigeon, Speckled	Granivore	GC+UR
Cormorant, Reed	Piscivore	GC	Plover, Grey	Other	GC
Cormorant, White-breasted	Piscivore	GC	Prinia, Karoo	Insectivores	GC
Crombec, Long-billed	Insectivores	GC	Robin-chat, Cape	Insectivores	GC+UR
Crow, Cape	Mixed diet	UR	Seedeater, Streaky-headed	Granivore	GC+UR
Crow, Pied	Vertebrate prey	GC+UR	Siskin, Cape	Granivore	GC
Domestic Goose	Mixed diet	GC	Sparrow, Cape	Granivore	GC+UR
Dove, Laughing	Granivore	GC+UR	Sparrow, House	Granivore	GC+UR
Dove, Lemon	Granivore	GC	Sparrow, Southern Grey-headed	Granivore	UR
Dove, Red-eyed	Granivore	GC+UR	Sparrowhawk, Black	Vertebrate prey	GC
Dove, Ring-necked (Turtle-dove, Cape)	Granivore	GC+UR	Sparrowhawk, Rufous-chested	Vertebrate prey	GC
Dove, Rock	Granivore	GC+UR	Spurfowl, Cape	Mixed diet	GC+UR
Drongo, Fork-tailed	Insectivores	GC+UR	Starling, Common	Mixed diet	GC+UR
Duck, African Black	Mixed diet	GC	Starling, Red-winged	Mixed diet	GC+UR
Duck, Maccoa	Mixed diet	GC	Stilt, Black-winged	Other	GC+UR
Duck, Muscovy	Mixed diet	GC	Sugarbird, Cape	Pollinator	GC+UR
Duck, Yellow-billed	Mixed diet	GC	Sunbird, Amethyst	Pollinator	GC
Eagle, Booted	Vertebrate prey	GC+UR	Sunbird, Malachite	Pollinator	GC+UR
Eagle, Verreaux's	Vertebrate prey	UR	Sunbird, Orange-breasted	Pollinator	UR
Egret, Little	Mixed diet	GC+UR	Sunbird, Southern Double-collared	Pollinator	GC+UR
Egret, Western Cattle	Mixed diet	UR	Swallow, Barn	Insectivores	UR
Falcon, Peregrine	Vertebrate prey	GC	Swallow, White-throated	Insectivores	GC+UR
Fiscal, Southern (Common)	Insectivores	GC+UR	Swamp-warbler, Lesser	Insectivores	GC
Fish-eagle, African	Mixed diet	UR	Swift, Little	Insectivores	UR
Flycatcher, African Dusky	Insectivores	GC+UR	Tern, Common	Piscivore	GC

Flycatcher, Fiscal	Insectivores	GC+UR	Tern, Sandwich	Piscivore	UR
Goose, Egyptian	Mixed diet	GC+UR	Tern, Swift	Piscivore	UR
Goose, Spur-winged	Mixed diet	GC	Thick-knee, Spotted	Insectivores	GC+UR
Grebe, Little	Other	GC	Thick-knee, Water	Other	GC
Greenbul, Sombre	Mixed diet	GC	Thrush, Olive	Mixed diet	GC+UR
Guineafowl, Helmeted	Mixed diet	GC+UR	Tit-babbler, Layard's	Insectivores	GC
Gull, Hartlaub's	Mixed diet	GC+UR	Wagtail, Cape	Insectivores	GC+UR
Gull, Kelp	Mixed diet	GC+UR	Waxbill, Common	Granivore	GC+UR
Harrier-Hawk, African	Mixed diet	GC	Waxbill, Swee	Granivore	GC+UR
Heron, Grey	Mixed diet	GC	Weaver, Cape	Granivore	GC+UR
Hobby, Eurasian	Mixed diet	UR	White-eye, Cape	Mixed diet	GC+UR
Honey-buzzard, European	Insectivores	GC	Whydah, Pin-tailed	Granivore	GC+UR
Honeyguide, Lesser	Insectivores	GC	Woodpecker, Olive	Insectivores	UR

[Note: Golf Course: GC; Urban Area: UR]

Table 4: Raw Diversity (H), Evenness (E) and Richness (R) data from all the golf courses and urban areas sampled

	Golf Course			Urban		
	Diversity (H)	Evenness (E)	Richness (R)	Diversity (H)	Evenness (E)	Richness (R)
Clovelly	2.78	0.79	33.00	2.55	0.79	25.00
Durbanville	2.77	0.77	36.00	1.95	0.58	29.00
Erinvale	2.39	0.69	32.00	2.70	0.83	26.00
Heldeburg	2.77	0.80	32.00	2.25	0.73	22.00
King David Mowbray	2.30	0.71	26.00	1.75	0.61	18.00
Metropolitan	2.74	0.80	31.00	1.99	0.63	24.00
Rondebosch	2.38	0.70	30.00	2.09	0.64	26.00
Simonstown	2.68	0.78	31.00	2.47	0.84	19.00
Steenberg	2.54	0.69	39.00	2.65	0.81	27.00
Westlake	2.07	0.64	26.00	2.12	0.83	13.00