Woody Cover and Birds

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Abstract

Major influences on biodiversity in general and on species distributions in particular have occurred on South African landscapes over time as a result of human activities and climate change. Landscapes in southern Africa are not only a product of changes in climate, but they are also a product of the changes brought about by people and their land management practices. In recent decades, bush encroachment has increased dramatically throughout the Savanna Biome of South Africa. Bush encroachment is a vegetation dynamic of global interest. It refers to the thickening or increase of woody vegetation (trees and shrubs) at the expense of grasses and/or herbaceous vegetation. In many areas across South Africa, systems that were once open grassland have become dense thickets dominated by trees and shrubs. Bush encroachment is driven by global factors like increasing carbon dioxide (CO_2) levels in the atmosphere as well as local factors like grazing pressures and fire management practices.

In Africa, it has long been recognized that there is an influence of vegetation patterns and structure on the distribution and abundance of birds. Changes in habitats due to an increase or decrease in woody cover has been linked to changes in bird diversity and community structure. This thesis looks at what impacts bush encroachment has had on bird distributions in eastern South Africa, with a special focus on the Kruger National Park as well as Palearctic migrants.

Chapter 2 of the thesis develops a new quantitative method to relate bird distributions to woody cover. The algorithm is experimental, and an important aspect of the chapter is to investigate whether the results obtained coincide with expectations. The approach first estimates the proportion of the bird species in an area which occur in each woody cover category in a region. It also calculates the proportion of the area of the region which is in each woody cover category. It then uses Jacobs Index to provide an estimate of the extent of preference/avoidance of each species for each woody cover category, on a scale that runs from +1 (the entire population of the species is in that woody cover category) to –1 (none of the population of the species is in that woody cover category). The method is tested on a region consisting of three one-degree grid cells spanning Mpumalanga, Limpopo and Gauteng which include a diversity of woody cover categories, from grassland (no woody cover) to savanna to dense woodland.

Chapter 3 applies this approach to the birds of the Kruger National Park, examining which species have distributions which can, and which cannot, be explained to a greater or lesser extent by a preference for a particular range of

woody covers. Bird species are selected for close monitoring for ecological management purposes of the Kruger National Park.

Chapter 4 considers a set of 10 bird species, all of which are migrants to South Africa from Eurasia, and occur to a large extent during their non-breeding period within the savanna biome of South Africa. For each species, the extent of increase in relative abundance between the first and second bird atlas projects in the region (SABAP1 and SABAP2) is estimated. In most cases, the change of relative abundance can be explained in terms of bush encroachment. The likely provenance of these species in Eurasia is considered; for most species, this area lies in southwestern Asia, i.e. the Ukraine and adjacent Russia. Changes in habitat in this region are also considered and help to improve the understanding of how the populations in South Africa have changed.

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Contents

CHAPTER 1

Introduction: The Savanna Biome, and Bush Encroachment in Southern Africa

The Savanna Biome

What defines the Savanna Biome?

The Savanna Biome is extensive globally and in Africa, covering about 20% of the Earth's land surface and about half of Africa's land surface (Stevens et al. 2017). Globally, the Savanna Biome also contributes 30% of terrestrial net primary production, which is important for the global carbon cycle (Grace at al. 2006). It is the largest biome in South Africa, covering almost 50% of the landmass (Rutherford and Westfall 1994). Savanna woodlands, defined by having a grassy understory and a woody upperstory of trees and shrubs, and scrubland are the dominant habitat types across most of northern and eastern South Africa (Figure 1.1) (Allan et al. 1997).

One of the most important factors determining whether an area is or could become a savanna, is climate (Holdridge 1947, Stephenson 1990, Scholes and Walker 2004, Woodward et al. 2004). Globally, savannas are generally located in an east-west zone along the mid-latitudes between the tropical equatorial forests and the arid deserts of the world (Scholes and Walker 2004). In general, savannas are found in areas with a mean annual rainfall of 350 to 1000 mm, although some savannas are found in higher rainfall areas (Scholes and Walker 2004). Lower rainfall areas tend to have more fine-leaved *Vachellia* and/or *Senegalia* trees, whereas broad-leaved trees tend to occur in higher rainfall areas. Although climate does play an important role, some studies have found that savannas can exist even where the climate, soils, and topography favour forests (Swaine et al. 1992, Moreira 2000, Russell-Smith et al. 2003, Bond 2008).

Another factor to consider is geology. The underlying geology of an area and how it is influenced by the climate (weathering) determines the soil types (Scholes and Walker 2004). The soil type/structure and nutrient content in turn influence the vegetation types. Especially in savanna habitats which are not too dry or too wet, the soil characteristics play a significant role in determining plant communities (Scholes and Walker 2004).

Fire also plays a key role in maintaining savanna habitats (Bond and Keeley 2005, Staver et al. 2011, Simon and Pennington 2012). Fire is an important ecological process which influences the structure of savanna ecosystems, especially in relatively moist areas (Staver et al. 2011). A savanna is considered a moist savanna where the mean annual rainfall is greater than 650 mm. In these savannas the tree layer is not limited by a lack of rainfall, but rather it is kept from reaching a closed canopy state due to frequent fires and browsing pressure (Bond and Keeley 2005, Sankaran et al. 2005). In such areas, the fire suppression will result in bush encroachment and woody cover dominance (Bond and Keeley 2005, Sankaran et al. 2005). The frequency of fires in moist savanna ecosystems is also more regular, because lower variability in rainfall results in the accumulation of sufficient fuel to support a spreading fire (Sankaran et al. 2005).

Trees may burn down to the ground but then re-sprout as multi-stemmed shrubs or small trees. Fires can influence the height, structure, and density of trees in savannas, with a cascading impact on the biodiversity which calls the savanna home (Bond and Keeley 2005). Open areas with low tree density often indicate the presence of regular, intense fires. Fire can be a key factor driving the distribution of many of the world's vegetation communities (Bond and Keeley, 2005, Bond et al. 2005, Bowman et al. 2009), through interactions with vegetation composition and structure. In Africa, climate constrains maximum tree cover, but tree cover varies substantially below that maximum (Sankaran et al. 2005), due to factors including fire and herbivory (Bucini and Hanan 2007, Bond 2008, Sankaran et al. 2008). Long time periods of fire exclusion can lead to an increase in woody vegetation and eventually to tree canopy closure (Hoffmann 1999, Durigan and Ratter 2006).

In the more arid areas, fire is a less dominant ecological disturbance. In arid savannas, characterized by a mean annual rainfall of less than 650 mm, the tree layer is limited by the lack of moisture (Balfour and Howison 2001, Sankaran et al. 2005). This means that in these environments, the elimination of fire will not necessarily lead to bush encroachment and a total dominance by woody vegetation. Fire frequency in arid savannas is also more erratic, as the variability in rainfall and herbivory often prevent the accumulation of sufficient fuel to support regular spreading of fires (Balfour and Howison 2001, Sankaran et al. 2005).

Fires are not the only phenomenon to shape the structure and distribution of the vegetation across a landscape. Herbivores, whether mammals or insects, play a role in shaping the vegetation structure and composition of savannas (Waldram et al. 2008). The abundance of grazing herbivores in an area will have an impact on the fuel loads through the removal of grass, thus influencing the occurrence and intensity of fires (Bond and Archibald 2003). Damage to woody plants by a range of animals (such as porcupines and elephants) affects their post-fire survival, their ability to compete with grasses, and thus their abundance and relative dominance across a landscape (Yeaton 1988, Bond and Archibald 2003, Van Wilgen et al. 2008).

Mega-herbivores such as elephants *Loxodonta africana*, buffalo *Syncerus caffer* and white rhinoceros *Ceratotherium simum* change the vegetation landscape through their feeding activities (Owen-Smith 1988, Waldram et al. 2008). Termites have a severe impact on savanna vegetation because of the sheer volume of their biomass in a system and have even been referred to as ecosystem engineers (e.g. Dangerfield et al. 1998).

There are multiple ways of classifying savannas and savanna woodland; the most frequent classification is based on the dominant tree species. Bird distributions are closely linked to geographical variables, especially the vegetation types of an area (Allan et al. 1997). So, it makes sense to track changes in bird distributions by looking at how the vegetation is changing. To understand the influence of vegetation patterns and structure on bird distributions, it is important to have an understanding of the Savanna Biome and the different types of savanna/woodland found within this biome.

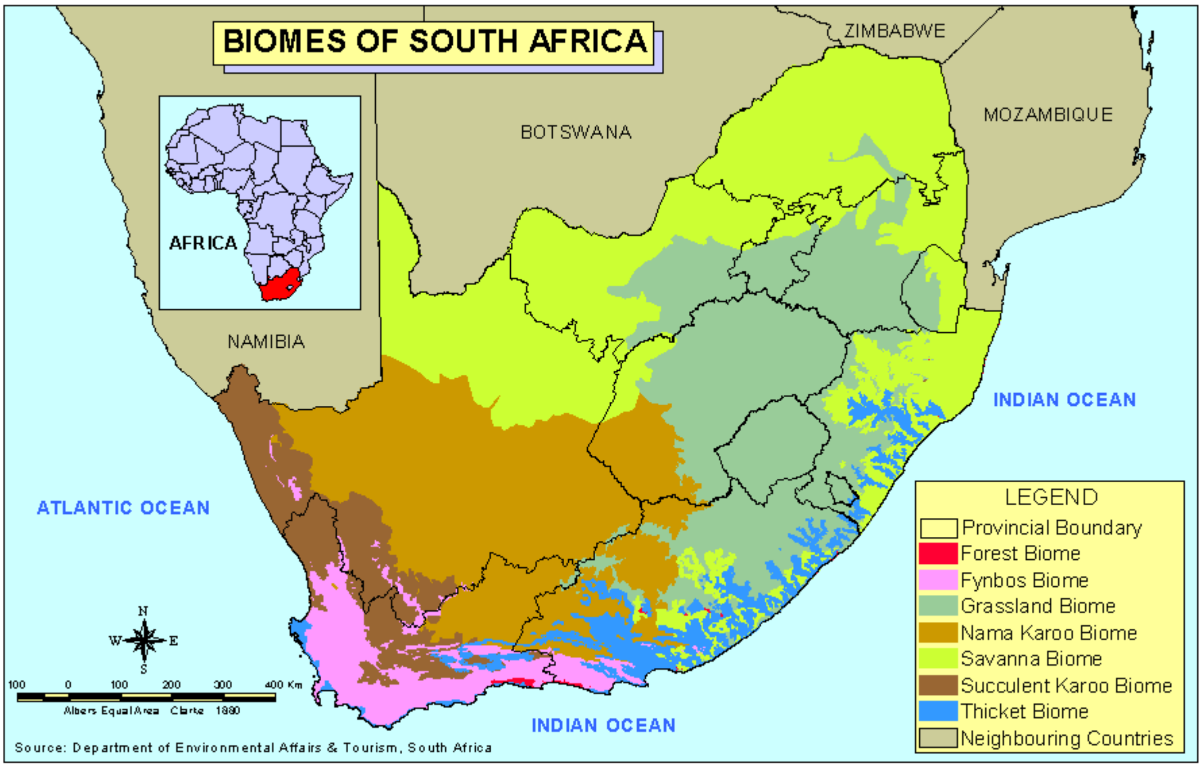

Figure 1.1 Biomes of South Africa (Department of Environmental Affairs and Tourism, South Africa 2000).

Savanna woodlands, also known as bushveld, lowveld, thornveld or tree savannas, cover northern KwaZulu-Natal, parts of Mpumalanga and Limpopo

Province, as well as parts of the Northern, Eastern Cape, and North-West Province in South Africa (Figure 1.1) (Berruti and Sinclair 1983). They also cover western Mozambique, Zimbabwe, Botswana and northern Namibia (Berruti and Sinclair 1983). Savanna woodlands vary with regard to tree species composition and vegetation structure. In drier areas *Senegalia/Vachellia* spp. (formerly *Acacia* spp.) predominate, but in wetter areas with suitable soils, the more abundant trees are the broader-leaved trees like Mopane *Colophospermum mopane* (Berruti and Sinclair 1983).

The characteristics that are usually used to define the type of savanna woodland are tree height, distance between trees and tree species composition, particularly the proportion of fine-leaved *Senegalia/Vachellia* species to broad-leaved deciduous species (Allan et al. 1997). The soil type is also an important defining character for savanna woodlands. Nutrient-rich clay soils tend to be dominated by thorny *Vachellia* species whereas sandy nutrient-poor soils tend to support the growth of broad-leaved tree species like Mopane. Savanna woodlands have been separated into different types in the literature. Some of these are described in more detail below:

Brachystegia/Miombo woodland

This woodland type, which is associated with trees from the genera *Brachystegia, Julbernardia* and *Isoberlinia*, extends across central Zimbabwe and into Mozambique, southern Zambia and Malawi. In general, Miombo tree species are broad-leaved species, which are relatively tall and can form a dense canopy (Allan et al. 1997). Nearly 500 bird species have been recorded in this woodland type, but none of these birds are strictly endemic to Miombo (Barnes 1998). Rainfall in this woodland type can vary from 650 to 1400 mm annually.

Mopane woodland

This woodland type is dominated by the broad-leaved Mopane tree (Allan et al. 1997). While Mopane woodlands (sometimes referred to as Mopaneveld) are dispersed throughout southern Africa, they are bounded by the Luangwa River (Zambia) in the north and the Pongola River (South Africa) in the south (White 1983). Mopane woodlands can vary from tall trees with an open understorey to a dense scrubland (Allan et al. 1997). This type of woodland occurs where the average rainfall is >450 mm per year.

Kalahari Vachellia-Baikiaea woodlands

African Teak or Zambezi Teak *Baikiaea plurijuga*,is a species of legume in the Fabaceae family. The Kalahari sands occur in a wide belt along the Angolan-

Namibian border, through Botswana and into Zimbabwe, supporting dry deciduous savanna woodlands dominated by *Baikiaea plurijuga* (Moyo et al. 1993). More than 400 species of bird have been recorded in this type of woodland, including the Southern Ground Hornbill *Bucorvus leadbeateri* and in the *Baikiaea* dominated woodland, the near-endemic Bradfield's Hornbill *Tockus bradfieldi* (Barnes 1998). This woodland type can also form part of what is knowns as Arid Woodland (Allan et al. 1997). Kalahari *Vachellia-Baikiaea* woodlands receive intermediate and variable rainfall of 250 to 650 mm annually (Allan et al. 1997).

Northern Kalahari

This area is dominated by semi-deciduous to deciduous *Vachellia*, *Terminalia* and *Combretum* trees that form dense scrub- or woodlands on deep Kalahari sands (Allan et al. 1997). The Northern Kalahari savanna has variable summer rainfall of 400 to 550 mm annually (Allan et al. 1997).

Central Kalahari

This type of woodland savanna also occurs on deep Kalahari sands, and is dominated by semideciduous *Vachellia* spp., Shepherd's Trees *Boscia albitrunca,* Silver Cluster-leaf trees *Terminalia sericea* and Kalahari Apple-leaf trees *Lonchocarpus nelsii* (Allan et al. 1997). The Central Kalahari is also associated with sparse to dense scrubland with variable grass cover (Allan et al. 1997). The average annual rainfall ranges from 110 mm to more than 500 mm in some areas (Thomas and Shaw 1991).

Southern Kalahari

The Southern Kalahari savanna forms open scrubland with semi-deciduous *Vachellia* spp. and *Boscia albitrunca* trees on deep Kalahari sands. This type of savanna is characterized by hot summers and cold winters with an average rainfall of <250 mm per year (Allan et al. 1997).

Vachellia woodlands

This type of woodland is also known as thornveld savanna and it is dominated by fine-leaved *Vachellia* species (especially Knobthorn *Senegalia nigrescens*, Scented-pod Thorn *Vachellia nilotica* and Red Thorn *Vachellia gerrardii*). This type of woodland/savanna is usually found on nutrient-rich soils (Chidumayo and Gumbo 2010). It can also form part of Arid Woodland with intermediate and variable rainfall of 250 to 650 mm annually (Allan et al. 1997).

Moist Woodland

A diverse plant community consisting of mainly broad-leaved tree species like *Combretum apiculatum*, *Vachellia caffra, Burkea africana* and *Faurea saligna* (Allan et al. 1997). Average rainfall per year ranges from 350 to 1000 mm.

Valley Bushveld

This is a dense scrubland with very little grass cover and almost impenetrable thickets of thorny shrubs, trees, succulents and creepers. This type of woodland is mainly found in hot, dry valleys in eastern South Africa (Allan et al. 1997).

From a bird distribution perspective, these various tree communities are important. The different woodland types are mixed and interspersed across the southern African landscape with some variations in between as soils, micro-climates, rainfall and elevations change from one area to the next. Crested Francolin *Dendroperdix sephaena*, Emerald-Spotted Wood Dove *Turtur chalcospilos*, Yellow-fronted Tinkerbird *Pogoniulus chrysoconus*, Black-headed Oriole *Oriolus larvatus* and Black-crowned Tchagra *Tchagra senegala* are all good examples of woodland birds and their ranges tend to show a strict boundary where grassland habitats start (Allen et al. 1997).

Another way of classifying savanna/woodland is by looking at the proportion of woody cover (Figure 1.2). Woody cover occurs as a continuum in the landscape and is described qualitatively from “sparse” to “an almost closed canopy” approaching forest (Allan et al. 1997). Where there are no trees, the habitat type is described as “grassland”. However, where trees are “sparse”, the ground is usually grassy depending on seasonal rainfall conditions and grazing intensity. Where trees form a canopy, the grass cover on the ground is usually sparse.

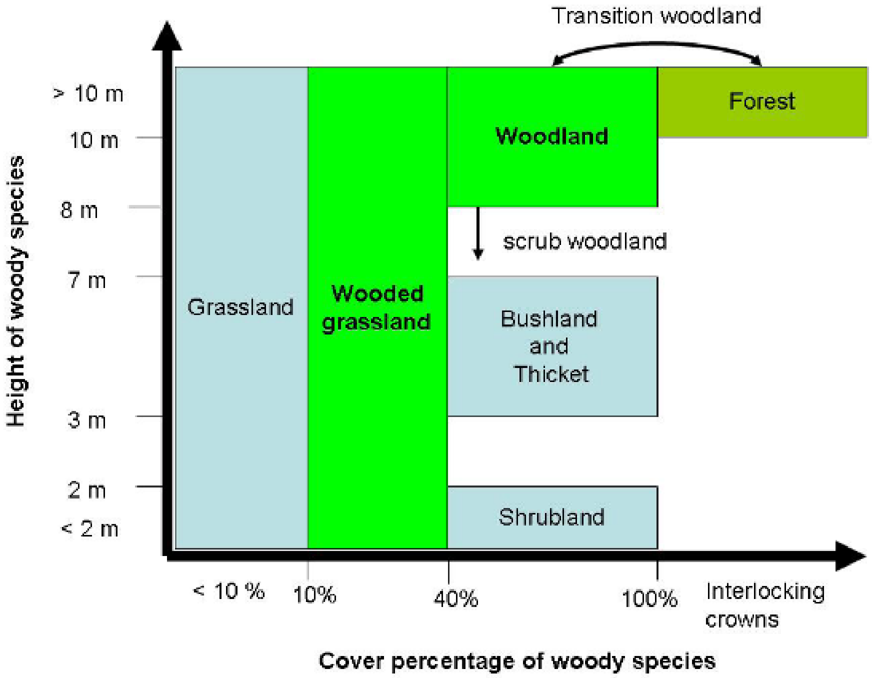

Figure 1.2 A basic classification of woody vegetation types. This graph shows the general height and cover percentage limits for the major vegetation physiognomic types. Transition woodland is woodland that oscillates between forest and woodland depending on the environmental/climatic conditions. Scrub woodland is a stunted form of typical woodlands, like scrub mopane woodland for example (Kindt et al. 2011).

Many bird species are described as occurring in woodland with various woody cover densities. In Volume One and Two of The Atlas of Southern African Birds, published in 1997, reporting rates in various vegetation types were given for each bird species (Harrison et al. 1997a, b). For example, Secretarybirds *Sagittarius serpentarius*, which prefer open habitats with scattered trees, had a 31.6% reporting rate in the Grassy Karoo vegetation type, 31.5% reporting rate in the Southern Kalahari and a reporting rate of only 5.7% in Valley Bushveld (Boshoff and Allan 1997). Crested Barbets *Trachyphonus vaillantii*, which prefer woodland habitats, had a 57.2% reporting rate in Moist Woodland, 38.1% in Arid Woodland and a reporting rate of 3.2% in Grassy Karoo vegetation types (Nuttall 1997). Crested Barbets were reported in other grassland habitats, but this can be attributed to the presence of exotic trees, gardens, parks, urban areas and homesteads that are scattered throughout these grassy biomes (Nuttall 1997).

The Savanna Biome is prone to rapid changes in vegetation composition and structure due to environmental changes (Stevens et al. 2017), therefore it is crucial that we monitor these changes closely for they will have an impact on the fauna (like birds) and people that call the Savanna Biome home.

Bush encroachment in the Savanna Biome

Stevens et al. (2017) found that bush encroachment is accelerating in African savannas and it is happening across various land-use types. Bush encroachment is a vegetation dynamic of global interest. It refers to the thickening or increase of woody vegetation (trees and shrubs) at the expense of grasses and/or herbaceous vegetation. In many areas across South Africa, systems that were once open grassland have become dense thickets dominated by trees and shrubs (O'Conner et al. 2014). Some of the major influences on species distributions and biodiversity are the changes that have occurred on South African landscapes over time as a result of human activities and climate change. Landscapes in southern Africa are not simply a product of changes in climate over time, but they are also a product of the changes brought about by people and their land management practices (O'Connor et al. 2014). In the past 30–40 years, bush encroachment has increased dramatically throughout the Savanna Biome of South Africa (O'Connor and Chamane 2012, O'Connor et al. 2014). Bush encroachment can impact the ability and capacity of savanna ecosystems to provide ecosystem goods and services such as grazing, for wildlife and livestock, and tourism by making it harder, for example, to view animals in parks. Bush encroachment affects the agricultural productivity and biodiversity of about 20 million hectares in South Africa (Ward 2005).

For these and many other reasons it is important that we understand what the key drivers of bush encroachment are. Bush encroachment or woody vegetation thickening is a global phenomenon. It is also important to recognize that the effects of bush encroachment can be positive or negative and the impacts on ecosystem functions vary from region to region around the world. For example, in eastern Australia, increases in woody cover have led to increases in abundance of some bird species, while others have showed declines (Ayres et al. 2001). In the Sabi Sands Private Nature Reserve (bordering the Kruger National Park) in eastern South Africa, Benshahar et al. (1992) found that managing bush encroachment through bush clearing had a positive effect for grazing herbivores like Blue Wildebeest *Connochaetes taurinus* and Plains Zebra *Equus quagga.*

The Savanna Biome is extremely important. The majority of the human population of Africa lives in this biome. The savanna also contributes significantly to primary production and plays a big role in the global carbon cycle (Grace et al. 2006). It is an important carbon sink, which is becoming an increasingly important factor in terms of climate change mitigation and carbon sequestration (Grace et al. 2006). Savannas are important to the livestock, wildlife and tourism industries in Africa, and many peoples' livelihoods depend on it (Peel 2005). Especially in southern Africa, the tourism industry plays a major role in the economy of the region. Therefore, a proper understanding of the ecological dynamics of the Savanna Biome is crucial for its conservation and to provide effective land management tools and guidelines. In South Africa, wildlife commands a high economic value, but this value is often hard to quantify. In general, the depletion of natural resources, ecosystem services and wildlife are not seen as having an impact on the economy or society (Davies 1997), but more and more people are starting to realize how crucial a healthy ecosystem and environment are to our own survival as a species. By demonstrating wildlife values and expressing them in monetary terms, wildlife is placed on an equal footing with other sectors of the economy. This provides important information for justifying and financing wildlife conservation, for using wildlife as a means of economic development and for setting in place economic activities that promote sustainable resource use.

There have been several drivers of bush encroachment in southern Africa, starting with a significant reduction of browsing herbivores at towards the end of the 19th century, due to a rinderpest epidemic as well as overhunting (Phoofolo 1993, O'Connor et al. 2014). This was followed by many years of fire suppression, which had been a conservative legislative land management policy across much of southern Africa (T. O'Connor pers. comm.). Cattle numbers in southern Africa started to increase in the early 1900s and reached a peak in the 1960s; this further reduced the competitive effect of grasses versus woody plants (O'Connor et al. 2014). The 1960s had also been a decade earmarked by drought, which meant that the peak cattle numbers degraded the grassy layers even further (O'Connor et al. 2014). The drought period was followed by high rainfall in the mid–1970s, which favoured the growth of woody plants (O'Connor et al. 2014). In recent decades, the levels of carbon dioxide in the atmosphere have increased dramatically and this also influences the increase in woody vegetation growth (Wigley et al. 2010). Stevens et al. (2017) argued that the main factors influencing bush encroachment are rising atmospheric CO_2 levels, changes in rainfall and changes in land management practices.

Bush encroachment is driven by global factors such as increasing carbon dioxide (CO_2) levels in the atmosphere as well as local factors like grazing pressures and fire management practices (O'Connor and Chamane 2012). It is predicted that increased levels of carbon dioxide in the atmosphere will drive an increase in woody growth over that of grasses (Higgins and Scheiter 2012). The reason for this is the different methods of carbon fixation used in the photosynthetic process of plants. There are three metabolic pathways for carbon fixation in photosynthesis. These are C_3, C_4, and Crassulacean acid metabolism (CAM). CAM photosynthesis is a strategy used by plants in arid/desert environments (Ranson and Thomas 1960) and is therefore of little importance in tree/grass interactions associated with bush encroachment. Most woody plants (trees and shrubs) use C_3 photosynthesis, whereas most grasses use C_4 photosynthesis and higher levels of carbon dioxide favours C_3 plants over C_4 plants (Higgins and Scheiter 2012) (Figure 1.3). Assessing and calculating the impacts of climate change, such as bush encroachment, is extremely important and is a big challenge facing science and human societies (Higgins and Scheiter 2012).

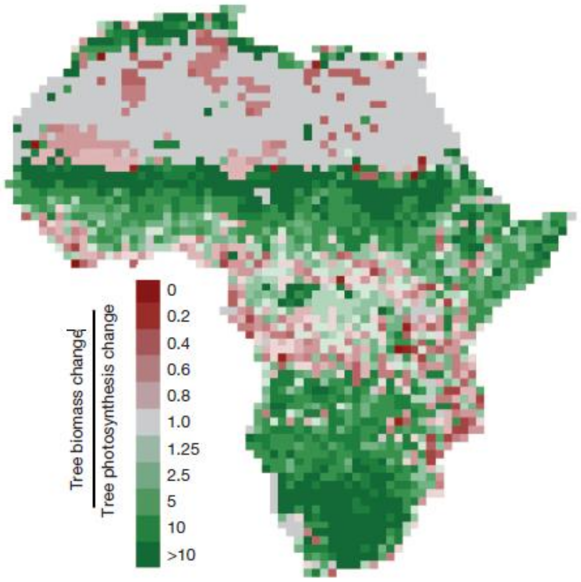

Figure 1.3 Predicted increase in tree biomass across Africa; with the areas shaded green showing predicted increases in woody cover by 2100 as compared to 1850 due to increases in CO_2 and fire interactions (Higgins and Scheiter 2012).

Several studies have linked factors such as overgrazing or a decrease in fire frequency, which would favour the survival and growth of woody vegetation over that of grasses, to bush encroachment (Scholes and Archer 1997, Hoffmann et al. 2012, Murphy and Bowman 2012). However, it seems that rising atmospheric CO_2 levels is one of the main causes of bush encroachment, leading to the expansion of savannas at the expense of grasslands (Higgins and Scheiter 2012). Water use efficiency by woody plants increases with increased CO_2 (De Boer et al., 2011), thus decreasing the water needed for growth. Therefore, increased CO_2 concentration leads to a shift in tree-grass competition for water, possibly favouring C_3 trees over C_4 grasses (Bond and Midgley 2000, Bowman et al. 2010, Kgope et al. 2010, Wigley et al. 2010).

Wigley et al. (2010) used aerial photography to measure changes in woody cover for three different land-use areas (conservation sites, commercial ranching, and communal rangelands) in the savannas of north-eastern KwaZulu-Natal Province, South Africa, at three time intervals (1937, 1960, 2004). They found highly significant increases in woody cover for all three sites. Total woody cover for conservation sites increased from 14% in 1937 to 58% in 2004, for commercial ranches this increase was from 3% to 50% and in communal farming areas woody cover increased from 6% in 1937 to 25% in 2004 (Wigley et al. 2010).

A comparison of aerial photographs taken in the eastern Lowveld savanna of South Africa in 1944 and in 1986 showed a clear change in vegetation structure and an increase in woody plant density over large areas of the Lowveld (Peel et al. 2004). The Lowveld, so called for its low-lying altitude of below a 1000 m above sea level, is located in north-eastern South Africa, where it is bounded by the Mpumalanga Province section of the Drakensberg Mountains in the west and the Lebombo Mountains in the east on South Africa's border with Mozambique (Emmett and Patrick 2010). Peel et al.'s (2004) findings agree with the physiognomic assessment (an assessment based on the appearance of something, used to gain insight into the characteristics of an area) undertaken by Gertenbach (1983) in the Kruger National Park. Gertenbach defined the various landscapes or ecoregions of the Kruger National Park based on their geomorphology, climate, soil and vegetation patterns and the associated fauna Both studies (Gertenbach 1983, Peel et al. 2004) concur that there has been an increase in and a densification of woody plants over time as well as a reduction in vegetation structural diversity. A good example of how much bush encroachment can alter a landscape is given by an important pair of photographs, one taken in 1955 with the same view repeated in 2012; these two photographs reveal the extent of bush encroachment at Spioenkop in KwaZulu-Natal Province, South Africa (Figure 1.4).

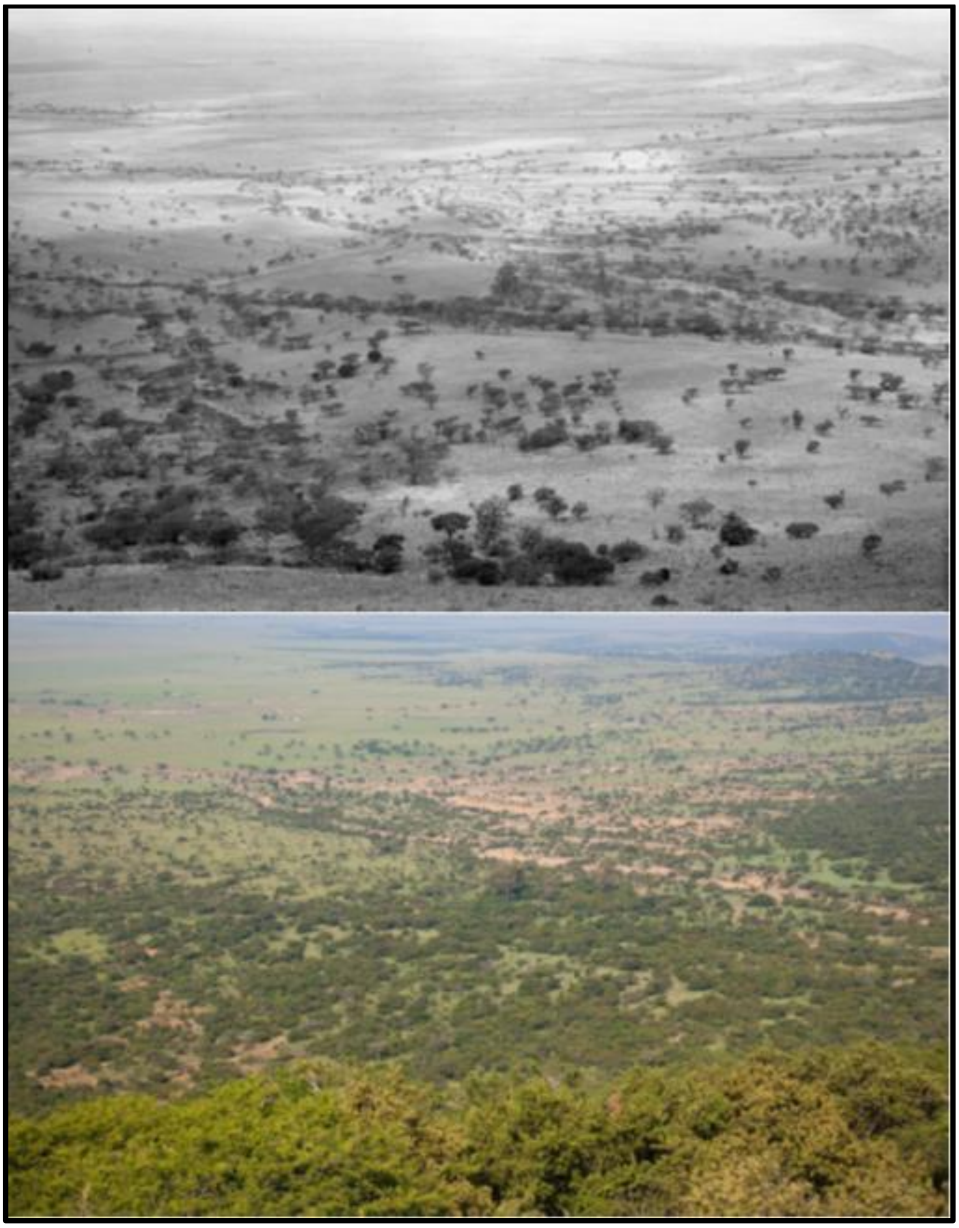

Figure 1.4 Example of bush encroachment from Spioenkop, KwaZulu-Natal Province, South Africa - Photos: top: Denzil Edwards, 1955; bottom: James Puttick, 2012 (Stevens et al. 2015a, Stevens et al. 2015b).

Bush encroachment has had an impact on a wide variety of taxa, their ranges and biodiversity, and it might be the key driving factor behind species range changes in the Savanna Biome of southern Africa (Loftie-Eaton 2014). Meik et al. (2002), for example, found that bush encroachment has a negative impact on the diversity of lizard species in central Namibia. This is an area where bush encroachment has an important influence on how the land is utilised. Meik et al. (2002) found that their results are consistent with the accumulating evidence that suggests bush encroachment and its related ecological impacts are changing the diversity and function of savanna ecosystems throughout southern Africa.

Bush Encroachment and Bird Distributions

Several studies have described the impacts of bush encroachment on bird distributions and diversity. They are summarized here.

Péron and Altwegg (2015) used data from the two Southern African Bird Atlas Projects (SABAP1 and 2) and investigated the non-climatic factors that have influenced bird distributions over the past 25 years. They found that, in the context of bush thickening, birds considered to be closed-savanna (more woody) specialists have increased in abundance whereas the open-savanna (less woody) specialists have decreased.

A study conducted in Swaziland by Sirami and Monadjem (2012) documented how bird communities had changed between 1998 and 2008 due to bush encroachment. They found that changes in species occurrence were significantly influenced by species habitat preference. Species that increased significantly in abundance were those associated mainly with wooded savanna vegetation, whereas species that decreased significantly were associated mainly with open savanna (Sirami and Monadjem 2012). They found that bush encroachment favoured certain species, but it also resulted in decreased species diversity.

Herremans (1998) conducted a study on the impacts of land-use on the conservation status of Botswana's birds. He found that birds associated with thornveld (scrub and woody savanna) benefitted from bush encroachment. Their reporting rates were also highest specifically on unprotected land where overgrazing by livestock had led to an increase in woody cover. About half of the species typical of the Kalahari basin are thornveld species, and this group of birds, which includes 18 regional endemics, had benefited from bush encroachment (Herremans 1998). Reporting rates of large grassland birds and birds associated with grass cover were much lower on unprotected, bush encroached, land (Herremans 1998).

The consequences of bush encroachment for birds does not only occur in savanna habitats. It also has an impact in the tundra of the Northern Hemisphere, where northward shifts of habitats and bird distributions are likely to be driven by several factors including the 'shrubification' of tundra and northward expansion of predators and competitors (Wauchope et al. 2016). Pearson et al. (2013) conducted a study on vegetation shifts in the Arctic due to climate change. They predict that woody cover will increase by as much as 52% and this will have a positive feedback effect on climate change (Pearson et al. 2013). It is projected that climate change will increase the relative abundance and cover of woody plant species in high-latitude tundra ecosystems (Myers-Smith et al. 2010).

Overview of thesis

The primary focus of this thesis is to devise a new strategy for quantifying the woody cover preferences of birds in north-eastern South Africa, with special attention given to the Kruger National Park and to Palearctic migrants. The knowledge of woody cover preferences is a critical precursor to understanding the impacts which bush encroachment has on bird distributions.

Chapter 2 develops a new quantitative method to relate bird distributions to woody cover. The approach first estimates the proportion of the total bird species in an area which occur in each woody cover category in a selected region. It also calculates the proportion of the area of the selected region which falls into each woody cover category. It then uses Jacobs Index to provide an estimate of the extent of preference/avoidance of each species for each woody cover category, on a scale that runs from +1 (the entire population of the species is in that woody cover category) to –1 (none of the population of the species is in that woody cover category). The experimental method is tested on a region consisting of three one-degree grid cells spanning Mpumalanga, Limpopo and Gauteng Provinces. This region was chosen because a large volume of SABAP2 data are available, and because it includes a diversity of woody cover categories, from grassland (no woody cover) to savanna to dense woodland.

Chapter 3 applies this same method to the Kruger National Park, the flagship national park of South Africa and an apparent safe haven for wildlife and biodiversity. I examine which species have distributions which can, and which cannot, be explained to a greater or lesser extent by a preference for a particular range of woody covers. Bird species are selected for close monitoring for ecological management purposes of the Kruger National Park.

Chapter 4 considers a set of 10 bird species, all of which are migrants to South Africa from Eurasia and occur to a large extent during their non-breeding period within the savanna biome of South Africa. For each species, the extent of increase in relative abundance between the first and second bird atlas projects in the region (SABAP1 and SABAP2) is estimated. In most cases, the change of relative abundance can be explained in terms of bush encroachment. The likely provenance of these species in Eurasia is considered; for most species, this area lies in southwestern Asia, i.e. the Ukraine and adjacent Russia. Changes in habitat in this region are also considered and help to improve the understanding of how the populations in South Africa have changed.

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CHAPTER 2

The Relationship Between Woody Cover and Bird Species Distribution

Introduction

In Africa, it has long been recognized that there is an influence of vegetation patterns and structure on the distribution and abundance of birds (Chapin 1923, Moreau 1966). In 1923, Chapin wrote; "The key to an understanding of present–day bird distribution in Africa will be found in ecological conditions, especially the nature of the vegetation, which is an index of the climate". Within southern Africa, the diversity and abundance of bird species is closely linked to habitat structure (Hockey et al. 2005). Changes in habitats due to an increase or decrease in woody cover has been linked to changes in bird diversity and community structure (Parmesan and Yohe 2003, Skowno and Bond 2003, Sirami et al. 2009, Eldridge et al. 2011). The study by Sirami et al. (2009) suggested that bush encroachment is probably one of the main drivers of bird distributions and population dynamics in the savannas of southern Africa. And, if current trends of woody cover thickening continue it could negatively impact several bird species that are associated with open savanna in southern Africa (Sirami et al. 2009). Bush encroachment in savanna and grassland environments is a global phenomenon that has come to the forefront as a land management concern, especially in the last 50 years (Skowno et al. 2016). In general, bush encroachment is perceived as a threat to the productivity and biodiversity of rangelands like savannas and grassland ecosystems (Skowno et al. 2016). Skowno et al. (2016) attempted to provide the first comprehensive estimate the extent of woody cover change in the savanna biome of South Africa, based largely on Landsat imagery,

Recent advances in the processing of satellite imagery have made it possible to shift the paradigm from qualitative descriptions of woody cover to fine-scale quantitative measurements. Woody vegetation cover across a landscape is the simplest and most widely used structural metric (Mathieu et al. 2013). When woody cover is combined with the height of the vegetation in an area, it provides a good volumetric indicator, which is more informative, and is easy to calculate (Mathieu et al. 2013). Mathieu et al. (2013) assessed the usefulness of multitemporal polarimetric RADARSAT-2 C-band imagery to map measures of woody volumetric indices in the Lowveld savanna of north-eastern South Africa. Remote sensing is helping to contribute to a better understanding and assessment of biodiversity-related characteristics across a landscape, providing accurate, and more cost-effective ways of measuring the factors, like woody cover, that influence biodiversity (Petrou et al. 2015).

In this chapter, I use bird atlas data from the Second Southern African Bird Atlas Project (SABAP2) and quantitative measures of woody cover based on LiDAR systems, and developed by Naidoo et al. (2015), Mathieu et al. (2013) and Cho et al. (2012) to explore the extent to which this measure of woody cover is influential in explaining bird distributions.

For each species, this chapter develops an algorithm which relates the estimated relative abundance of the bird species recorded within a pentad to a description of the woody cover of the pentad. The output for each species is a "signature" which describes its woody cover preference-avoidance strategy over 20 categories of woody cover. The signatures for the species are then classified, using non-hierarchical clustering, to try to establish if there are groups of species with similar woody cover preferences. The clustering algorithm produces an average "signature" for the species in each group. A distance between each group signature is calculated, and the resulting dissimilarity matrix subjected to multidimensional scaling, which ought to generate a plot in which groups with similar group signatures are plotted close together. Given that there is no guarantee that the proposed algorithm will generate groups which are ecologically sensible, two important components of this chapter are (1) to evaluate whether the groups formed are compatible with known woody cover preferences, and (2) to develop insights into the functioning of the algorithm, and especially to examine the performance of the plot resulting from the multidimensional scaling.

This chapter is primarily methodological, using the newly available quantitative LiDAR data for woody cover to present an approach to answering the questions: "Do bird species have preferred woody cover densities? To what extent do these match up with our expectations?" The study area for this chapter includes habitats ranging from grassland to well-developed savanna (Allan et al. 1997) and is therefore well-suited to testing the algorithm. Chapter 3 then applies this approach to bird distributions in the Kruger National Park, which consists almost entirely of savanna habitats.

Methods

Exploratory data analysis

John Tukey (1915–2000), an influential person in the development of statistical thinking, famously split data analysis into two broad categories: exploratory data analysis and confirmatory data analysis (McCullagh 2003). He considered that too much emphasis was placed on confirmatory model building, and too little on exploring data. The approach to data analysis in this chapter (and in Chapters 3 and 4) is entirely and unashamedly exploratory. Exploratory data analysis can be defined as arithmetical algorithms designed to highlight the interesting features of a set of data. The product of the analysis is frequently a graphical display, interpretation depends on a visual assessment, which is potentially subjective (Tukey 1977). Five-number-summaries, stem-and-leaf plots, and box-and-whisker plots are three of many methods in exploratory data analysis devised by John Tukey, in a varied career which spanned six decades and multiple disciplines, and who was the master-craftsman of data analysis (McCullagh 2003). These exploratory methods can be evaluated as successful if they enable complex properties of the data to be visualized rapidly. McCullagh (2003), described the domain of exploratory data analysis, developed by John Tukey, as "a world rich in examples, where the rules are unclear, and the guiding principles are as likely to be found in psychology as in mathematics or probability." To help evaluate whether the product of the exploratory data analysis is useful, two key questions can be asked: (1) Is the product a reliable summary of the raw data? (2) Does it communicate the essential features of the data faithfully? These issues will be addressed further in the Discussion.

The woody cover analysis developed here is fairly similar to the approach used for the "habitat-type" analysis in the First Southern African Bird Atlas Project (SABAP1) (Harrison and Underhill 1997), which is described there in the section on "Vegetation analysis". This habitat-type analysis could also be categorised as an exploratory data analysis. It helped to uncover some of the important factors linking habitat to bird distributions. It generated hypotheses, which would need to be followed by confirmatory analyses to aid in the assessment of statistical significance.

Harrison and Underhill (1997) pointed out a bias in this method, and that bias applies to the analysis presented here as well. The bias is a consequence of the unit of data collection being the grid cell, in which there can occur multiple woody cover classes. This results in species being associated with woody cover classes in which they do not occur. This bias is greatly reduced in analyses based on SABAP2 data, compared with SABAP1, because there a nine SABAP2 pentads in one SABAP1 quarter degree grid cell.

Study area

The study area chosen for this analysis consisted of a transect mostly through Mpumalanga Province and north-eastern Gauteng Province in South Africa (Figure 2.1). The study transect consisted of three degree cells, 2528, 2529 and 2530, in the standard South African nomenclature. This is the area between 25°S and 26°S, and between 28°E and 31°E. This transect was selected because it is at the interface between Savanna Biome and the Grassland Biome and because it has large volumes of SABAP2 atlas checklists (Figure 2.1). The potential transect immediately to the north had far less data, and the transect to the south would have been mostly in the Grassland Biome.

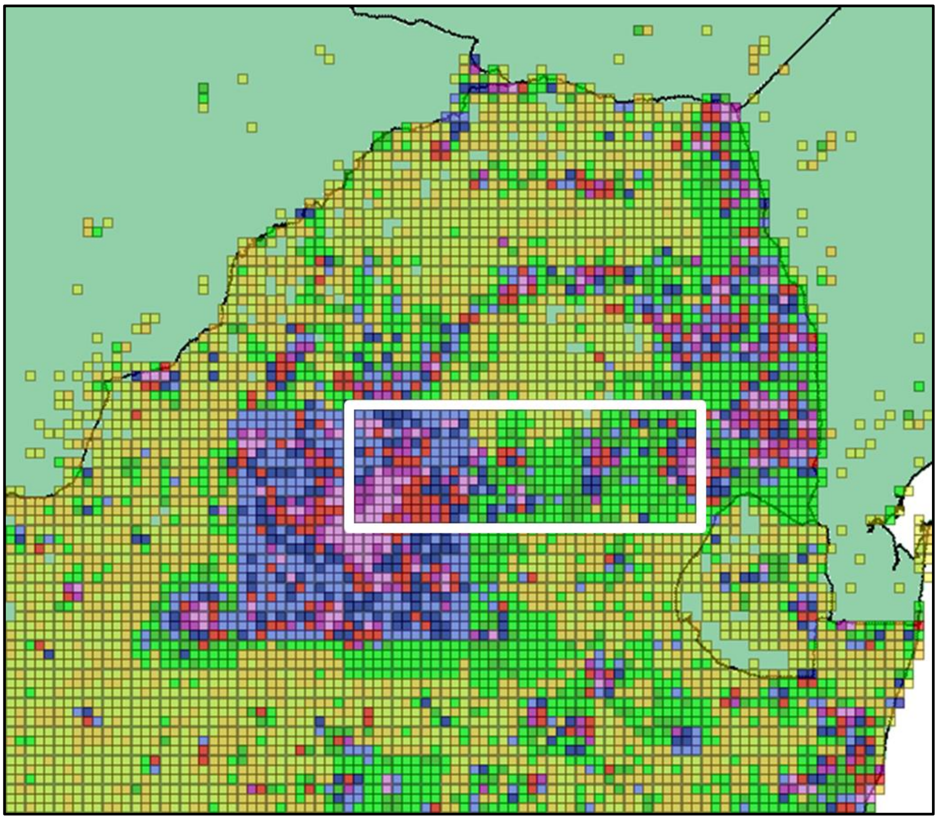

Figure 2.1 Location of Study transect in relation to the rest of South Africa. All pentads (5 minutes of latitude by 5 minutes of longitude) within the study transect have data, most of them have at least four full protocol checklists submitted (i.e. at least eight hours of intensive bird atlasing completed; green or darker colours) and several pentads have 11 or more full protocol checklists submitted (i.e. more than 22 hours of atlasing; light blue, dark blue, red, purple and pink colours).

Two datasets for the study transect were used in the exploratory data analysis: a woody cover dataset; and the bird atlas data collected by SABAP2. The methods to obtain the two datasets are explained in more detail in sections below.

Woody cover data: LiDAR

Woody cover density data were obtained from the Council for Scientific and Industrial Research (CSIR) in Pretoria. Their data on woody vegetation cover is obtained through Light Detection and Ranging (LiDAR) and Synthetic Aperture Radar (SAR). LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth (Naidoo et al. 2015). In South African savannas, this meant using a combination of X-band (TerraSAR-X), C-band (RADARSAT-2) and L-band (ALOS PALSAR) radar datasets (Naidoo et al. 2015). This approach is more effective at quantifying the woody component of an environment than regular remote sensing techniques, because LiDAR and SAR are not affected by clouds or shadows. These methods, therefore, are able to detect structural parameters within the canopy of the vegetation such as canopy cover, tree height, above ground biomass and total woody canopy volume (Naidoo et al. 2015).

In the study transect, LiDAR data on the percentage woody cover for each pentad are available on a grid. The LiDAR data used in this chapter consisted of woody cover values on a grid of 0.005 minutes of latitude and longitude. Thus these values are on a c. 500 m pixel resolution. Thus, each LiDAR data point provided an estimate of the woody cover over a 25 ha plot, so that there were c. 400 woody cover estimates per pentad. The percentage of each pentad in each woody cover class was estimated based on the c. 400 woody cover points per pentad. 5% woody cover class intervals were used, 0–5%, 5–10%, …, 95–100%, for a total of 20 woody cover classes. Algebraically, let the proportion of woody cover class k in pentad j be h_{jk}. The percentage of the study transect in woody cover class k is denoted s_k and is found by summing over the pentads: $s_k = \sum_j h_{jk}$. Table 2.1 shows the proportions, expressed as percentages, of the study transect in each of the 20 woody cover classes. These percentages lay between 1.35% for the woody cover class 0–5% (which is essentially grassland) and 11.72% for the woody cover class 65–70% (which constitutes a well wooded savanna) (Table 2.1). Thus, no woody cover class either dominated the analysis or was totally excluded.

Table 2.1 Percentages of the study transect which fell into each of the 20 woody cover classes.

Woody cover class	Percentage of total area (%)
0–5%	1.35
5–10%	6.03
10–15%	5.07
15–20%	2.77
20–25%	2.55
25–30%	1.90
30–35%	2.10
35–40%	2.59
40–45%	6.39
45–50%	9.84
50–55%	6.43
55–60%	6.99
60–65%	7.98
65–70%	11.72
70–75%	10.19
75–80%	6.21
80–85%	4.51
85–90%	2.75
90–95%	1.59
95 100%	1.04

Bird data: Second Southern African Bird Atlas Project (SABAP2)

SABAP2 data are collected on a pentad scale. Pentads are 5 minutes of latitude by 5 minutes of longitude, comprising grid cells of approximately 9.2 km × 8.5 km. SABAP2 observers collected ordered checklists of species for each pentad. For full protocol checklists, observers must spend at least two hours in the pentad, birding intensely and covering as much of the pentad as possible. Standardizing the observer effort as much as possible strengthens the quality of the data (Harebottle et al. 2007). The reason for the two-hour minimum is motivated by the concept that within those two hours most species within a pentad with reasonably uniform habitat should be located by most bird atlasers (Harebottle et al. 2007). For pentads with more varied habitats and topography the time taken to locate most species is more than two hours. However, because of the way the SABAP2 protocol has been developed, observers are motivated to spend as much time in a pentad as needed in order to complete a full protocol species checklist. This observer motivation is explained by the concept of “gamification” (Ainsley and Underhill 2017).

The SABAP2 protocol has proven to be extremely useful when having to apply statistical analyses (Underhill et al. 2017). The statistical processes required to analyse the data were kept in mind when the SABAP1 and 2 protocols were designed (Underhill et al. 2017). In the world of modern statistical analysis raw data are considered to have two components: the "truth", what really is happening on the ground, and the "observer process", what the observer sees (Underhill et al. 2017). It is important to be able to tease out the ecological "truth" from what has been observed. The goal of SABAP2 is to help us answer fundamental and large-scale questions like: "How are bird distributions changing in southern Africa?", "What is the relationship between the changes that have occurred in the biomes of South Africa and the changes that have been observed in the distributions of birds?" And more specifically, questions such as: "Does the Kruger National Park make a difference to bird conservation?" (Underhill 2016) are critical for the conservation community including policy makers, researchers, reserve managers and educators.

The study transect has excellent SABAP2 data coverage (Figure 2.1). All pentads within the study transect have data, most of them have at least four full protocol checklists submitted (i.e. at least eight hours of intensive bird atlasing completed; shaded green or darker colours in Figure 2.1) and several pentads have 11 or more full protocol checklists submitted (i.e. more than 22 hours of atlasing; light blue, dark blue, red, purple and pink in Figure 2.1).

For the analysis, we only used pentads for which at least four full protocol cards have been submitted (i.e. comprising at least eight hours of birding). We used only species which occurred in 30 or more of these pentads within the study transect. The SABAP2 data for the pentads in the study transect was extracted from the SABAP2 database. For each species, the raw data consists of the number of checklists for each pentad, and the number of times the target species was recorded. The ratio of these two numbers provides the reporting rates for the species in each pentad in the study transect.

The Griffioen transformation

The next objective is to estimate the percentage of the total population of the target species which is in each pentad. This percentage needs to be calculated relative to the study transect. The available data consist of the reporting rates for the species in each pentad. The so-called "Griffioen transformation" enables a first estimate of these proportions to be made (Griffioen 2001, Underhill 2016). Peter Griffioen, in an unpublished PhD thesis (Griffieon 2001), based his transformation on mathematical ecology developed in a theoretical paper by Nachman (1984).

In algebraic terms, the algorithm that was used for this component of the exploratory data analysis is described here. For each species and for each pentad, define m_{ij} and n_j, where n_j is the number of checklists in a pentad j and m_{ij} is the number of checklists that report species i as present in pentad j. Then $r_{ij} = \frac{m_{ij}}{nj}$ is the reporting rate for species i in pentad j. Let d_{ij} be the density or relative abundance of the species i in pentad j. This can be in any units, for example birds/pentad. Next, follow Griffioen (2001), and define $d_{ij} = K_i(-\ln(1 - r_{ij}))$, where K_i is a species-specific constant of proportionality. The value of K_i clearly depends on the conspicuousness of the species, in other words its detection probability. The actual value of K_i is irrelevant, because it is only an estimate of the relative proportion that is needed in this analysis. Let $D_i = \sum d_{ij}$, the sum over the pentads, yielding the total number of birds in the study transect. Now let $g_{ij} = \frac{d_{ij}}{D_i}$. Then g_{ij} provides an estimate of the proportion of the total population of species i which is in pentad j. This is the point at which the actual value of K_i becomes irrelevant, because effectively it occurs in both the numerator and the denominator of the ratio and is cancelled out.

To recap, at this point, the relative abundance of species i across all pentads in the study transect has been estimated. In other words, the proportion of species i population in pentad j is calculated. This proportion g_{ij} is further subdivided into the proportion in woody cover class k in pentad $j : f_{ijk} = g_{ij}h_{jk}$. We now sum across the pentads to estimate the proportion of the population of species i in woody cover class k, denoted b_{ik}, in the study transect: $b_{ik} = \sum_j f_{ijk}$. This makes the assumption that the birds are uniformly distributed across the pentad, and this is where the bias mentioned in the second paragraph of Methods is introduced. Relating the bird data and the woody cover data for each pentad, the proportion of the population of the species which was at each woody cover class was estimated.

The estimated proportion of birds in each woody cover class per species and the proportion of the pentad that contains that woody cover class were used to calculate a measure of preference, using what is known as Jacobs' Index. Because the areas of the woody cover classes varied (Table 2.1), Jacobs' Index was used to remove the effect of varying areas of the woody cover classes.

Jacobs' Index

In spite of the fact that it was developed more than three decades ago, Jacobs' preference index (1974) has not been improved upon. Jacob's Index is a modification of earlier measures, the forage ratio and Ivlev's electivity index, and is a measure of the relation between resource use and resource availability (Jacobs 1974). This index has the following properties: it is independent of the relative abundance of the resource; it takes a value of zero under random selection (no preference) and deviates symmetrically from zero between –1 and +1; negative values indicate avoidance and positive values indicate preference (Jacobs 1974, Lechowicz 1982, Tjørve et al. 2008). These properties give Jacobs' Index advantages over alternative measures. Jacobs (1974) gave the expression for Jacobs' Index (D), where r is resource selection and p is resource availability, as follows:

$$D = \frac{r - p}{r + p - 2rp}$$

Assume that p, resource availability, is never 0. When r is 0, then none of the resource is used, and p is equal to –1, indicating complete avoidance. When r is equal to 1 (in other words, only this resource is used, to the exclusion of all others) then D is equal to +1. The values for D are thus constrained to lie between –1 and +1; negative values indicate avoidance and positive values indicate preference and a value of zero indicates no preference (Jacobs 1974, Tjørve et al. 2008).

In the context of this study, we have analogous values: r becomes the relative proportion of the total population of the birds of a species in a particular woody cover class, denoted b_{ik} above, and simplified here to b and p becomes the proportion of the total area that is in that particular woody cover class, denoted s_k above, simplified here to s. This generates the expression for Jacob's Index in this context:

$$D = \frac{b - s}{b + s - 2bs}$$

Other measures of preference also exist (Jacobs 1974). However, as Jacobs (1974) pointed out, they are "useless" when resource availability varies, as it does in this study (Table 2.1). As mentioned above, Jacobs (1974) demonstrated that the index he proposed is independent of the relative abundance of the resource; this is achieved by the introduction of the term $-2rp$ in the denominator of his original index (and the term $-2bs$ in the formulation used here).

For each species, the Jacobs' Index is calculated for each of the 20 woody cover classes. This provides a vector of length 20 for each species. Each value in the vector gives the strength of the preference (positive values) or avoidance (negative values) for each woody cover class. This vector can be thought of as the "signature" of the species in relation to woody cover class.

Non-hierarchical classification

I formed groups of species with similar “signatures” and a non-hierarchical classification was performed, as described by Friedman and Rubin (1967). Non-hierarchical classification divides the species into a predetermined number of groups, on the basis of their signatures, so that each group contains species with similar signatures. Various criteria exist to measure the performance of a particular grouping. The criterion I used maximizes the total Euclidean distance between the groups, which is the same as minimizing the sums of squares-within groups. This criterion is a looser alternative to one that assumes that the data consists of a mixture of multivariate normal distributions with a common covariance matrix. These two assumptions would not be true of the signatures for the bird species. The analysis was performed using the Cluster directive of Genstat Seventeenth Edition (2014). The number of groups selected was based on a judgement of when the criterion was no longer decreasing substantially as further groups were added (the “elbow” method) (Tibshirani et al. 2001). Since the objective is to undertake an exploratory data analysis, the subjective choice in this way is satisfactory. I computed the “average signature” for the species assigned to each group. I undertook a visual comparison of the signatures of the species assigned to a group and the average signature for the group. The average signatures for the groups were assembled into a rectangular data matrix with a row for each of the groups, and with 20 columns, one for each woody cover class. From this matrix, a dissimilarity matrix was constructed, using Euclidean distances between the rows of the rectangular matrix. The dissimilarity matrix was a symmetric matrix, with elements representing the Euclidean distances between the average signatures for each group of species.

Non-metric scaling

I used non-metric multidimensional scaling (Kruskal 1964; Greenacre and Underhill 1982) as implemented in GenStat Seventeenth Edition (2014) to transform the dissimilarity matrix into a configuration of points in two dimensions in which the ordering of the distances between the points matches the ordering of the distances between the groups in the dissimilarity matrix as closely as possible. Each point in this configuration represents one of the groups determined by the non-hierarchical cluster analysis. Groups with similar signatures are plotted close together. Careful inspection of the plot provides insights into the groups of particular interest, those groups with signatures which suggest they contain the species most sensitive to woody cover.

Results, and Discussion of the Groups

Together SABAP1 and 2 have amassed more than 16.5 million records on bird distribution for southern Africa and SABAP2 alone has amassed almost 9.5 million records for the region to date (Underhill et al. 2017). The total number of SABAP2 checklists for the study transect was 18,574, with an average of 57.1 species per checklist. The number of species that met the criteria for inclusion in this analysis was 451. The 451 “signatures” were too many to consider individually, so they were subjected to the non-hierarchical clustering. The “elbow method” suggested that 25 groups was a satisfactory choice. The average signature for each group was calculated, the group signature. A visual inspection showed that the signatures of the individual species within a group were similar to the group signature. The ordering of the groups in non-hierarchical clustering is arbitrary; there is no sense in successive groups being similar.

A 25×25 Euclidean dissimilarity matrix was calculated from the 25 group signatures. The individual elements of this data matrix represent the “distance” between two of the “group signatures”; if the group signatures are similar, the distance is small, and vice versa. This matrix was subjected to multidimensional scaling, and the “stress” of the configuration was 0.074, indicating a good representation of the dissimilarities of the input data matrix (Figure 2.2). In this plot (Figure 2.2), groups of species with similar group signatures ought to be plotted close together, and groups which are very different should be far apart.

A visual inspection of the configuration produced by the multidimensional scaling shows the points representing Groups 3 and 21 to be farthest apart in Figure 2.2. The signatures for these two groups were also extremely different; the signature for Group 3 showed strong preferences for little or no woody cover (open grassland), and that for Group 21 showed maximal woody cover (forest). Further exploration revealed that the groups which formed an “arch” along the upper edge of the plot of Figure 2.2 were the ones which contained the group signatures which peaked the most and had the smallest number of woody cover classes as preferences. In addition to this, the groups along the arch were ordered from left to right, following a natural progression of groups containing bird species which prefer mainly fairly open habitats on the left, to a series of groups which prefer increasing amounts of woody cover, to groups which prefer dense savanna woodlands, almost forests, on the right (Figure 2.2). The groups that are placed below the “arch” of Figure 2.2 turn out to be groups of species which can be ignored; either their preferences for woody cover are broad, or their habitat preferences are not related to woody cover.

This summary is expanded in more detail in the following paragraphs. For each group, I provide the woody cover preference plot, and give examples of four species contained within the group. Appendix 2.A contains the complete species lists and number of species per group. The consequence of the non-hierarchical clustering algorithm is that all the species within each group exhibit a similar signature; in this chapter the group signatures are presented (in a similar context, in Chapter 3, the signatures of individual species within the group are presented). To avoid the need to revisit each group in a Discussion section, comments on each group are included in this section. For a single species, a range change map between the first and second bird atlas is provided; this was done to illustrate the scope for studying range changes due to bush encroachment that this algorithm facilitates.

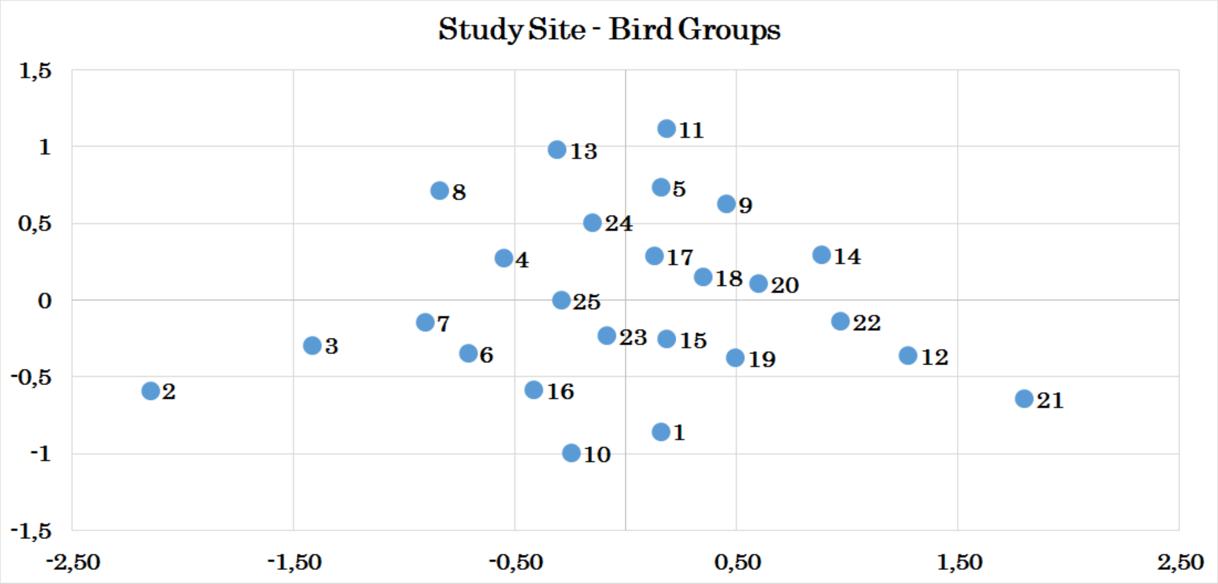

Figure 2.2 Bird groups for the study transect plotted using non-metric multidimensional scaling. The groups are numbered from Group 1 to Group 25 (see text as well as Appendix 2.A).

Group 2 includes species such as Spike-heeled Lark *Chersomanes albofasciata*, Ant-eating Chat *Myrmecocichla formicivore*, Long-tailed Widowbird *Euplectes progne*, and Eastern Clapper Lark *Mirafra fasciolata*. These birds prefer habitats with woody cover of less than 10% (Figure 2.3). These species prefer open grassy habitats (Hockey et al. 2005). Spike-heeled Larks prefer sparse grassland. Ant-eating Chats occur in open grassland and open savanna habitats. For eastern South Africa, the SABAP1 vegetation analysis for Ant-eating Chats showed that they prefer grassy habitats as opposed to woodland (Harrison 1997a). Eastern Clapper Larks' and Long-tailed Widowbirds' prefer open habitats such as grasslands (Hockey et al. 2005). These species would be sensitive to changes in woody cover and would most likely move out of an area at the onset or beginning stages of bush encroachment.

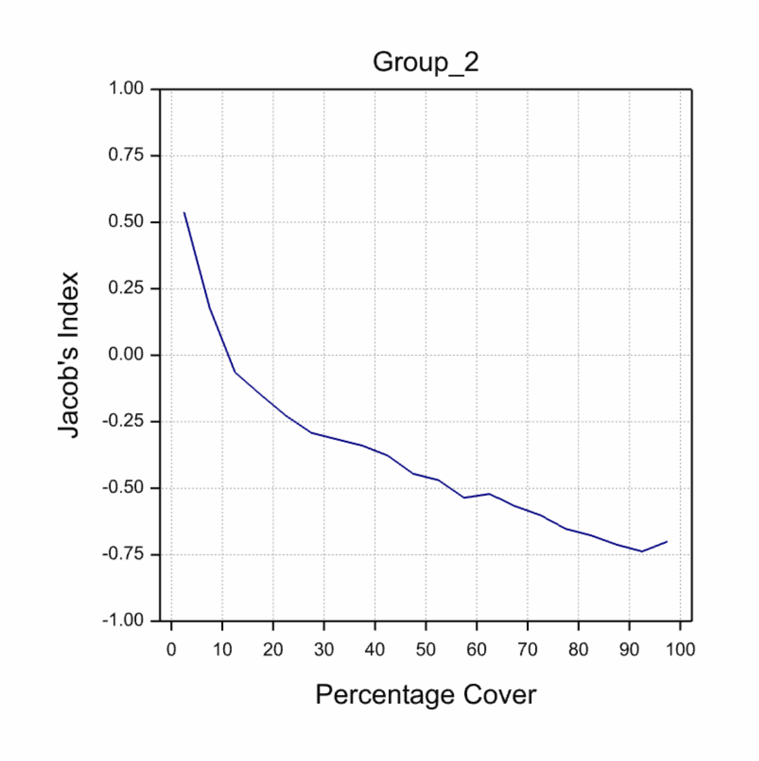

Figure 2.3 Woody cover preference plot for Group 2.

Group 3 includes species such as Melodious Lark *Mirafra cheniana*, Capped Wheatear *Oenanthe pileate*, African Quailfinch *Ortygospiza atricollis*, and Cape Longclaw *Macronyx capensis*. This group prefers areas with less than 15% woody cover (Figure 2.4). These species prefer open habitats (Hockey et al. 2005), but are more tolerant of some woody cover (less than 15%). Melodious Larks occur in open grassland areas. Reporting rates from SABAP1 indicated that these larks are more prevalent in sweet and mixed grassland type habitats (Dean 1997). Capped Wheatears prefer grassy plains, especially areas with bare ground, and semi-arid shrublands (Harrison and Herremans 1997). The preferred habitat of the African Quailfinch is that of short open grassland and Cape Longclaws also prefer grassland habitats (Hockey et al. 2005).

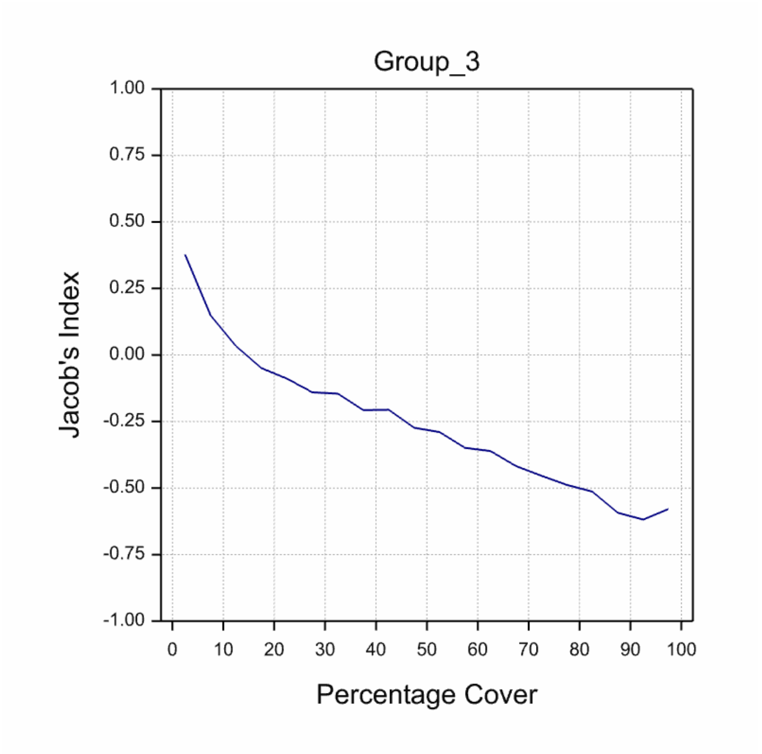

Figure 2.4 Woody cover preference plot for Group 3.

Group 8 contains species such as Black-chested Prinia *Prinia flavicans*, Marico Flycatcher *Bradornis mariquensis*, Sabota Lark *Calendulauda sabota*, and Scaly-feathered Finch *Sporopipes squamifrons*. Their woody cover preference ranges from 10% to about 40% (Figure 2.5). These species prefer habitats with scattered trees or shrubs, but not habitats that are too woody (Hockey et al. 2005). The Black-chested Prinia likes open *Vachellia* savanna with some scattered bushes, as well as fallow croplands. Marico Flycatchers prefer *Vachellia* savanna and open woodland (Herremans 1997). During the winter months, they tend to prefer more open habitats, moving into areas with more trees during the summer months (Herremans 1997). The preferred habitat of the Sabota Lark is that of savanna or open woodland and Scaly-feathered Finches prefer habitats with scattered small trees (Hockey at al. 2005).

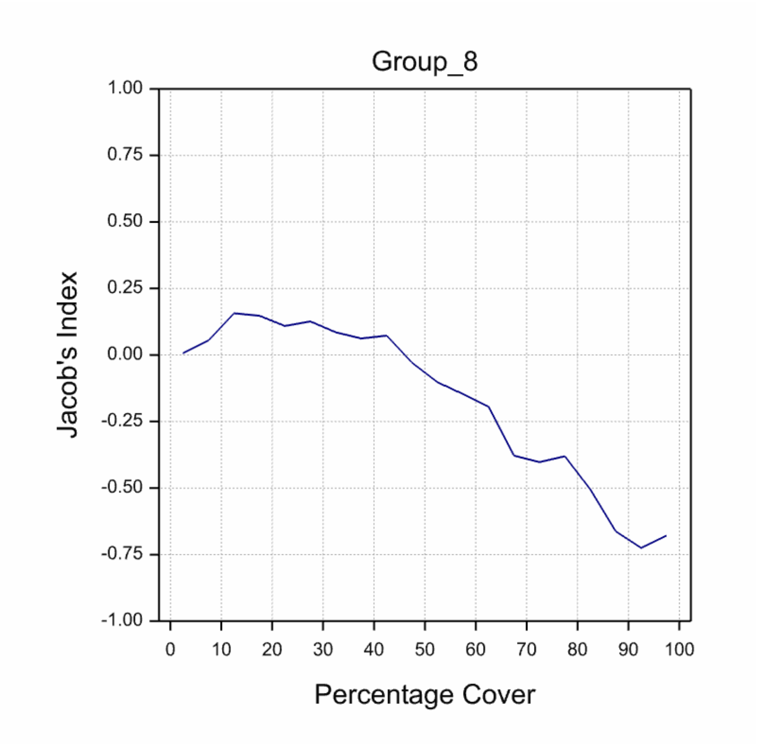

Figure 2.5 Woody cover preference plot for Group 8.

Group 13 includes Southern Ground Hornbill *Bucorvus leadbeateri*, Lilac-breasted Roller *Coracias caudatus*, Magpie Shrike *Corvinella melanoleuca* and Burchell's Starling *Lamprotornis australis*. Woody cover preference for Group 13 ranges from 10–55%, with peak preference of 20–40% (Figure 2.6). These species prefer a slightly broader range of woody cover than those of Group 8.

The species in this group prefer habitats with some woody cover (more than 10%), but when the habitat becomes too woody (more than 55%), preference drops sharply (Figure 2.6). Burchell's Starlings generally prefer open woodland and savanna, especially with Camel Thorn *Vachellia erioloba* and Knob Thorn *Senegalia nigrescens* trees (Hockey et al. 2005).

According to the individual woody cover preference plot for Southern Ground Hornbill, they avoid woody cover below 15%, preference peaks at a woody cover of about 35%, and they tend to avoid areas with woody cover above 60%. These findings match up with those of the Mabula Ground Hornbill Project (Lucy Kemp pers. comm.). The Southern Ground Hornbill is listed as Vulnerable globally and as Endangered in South Africa (Taylor et al. 2015). They are listed as Endangered in South Africa due to losing close to 70% of their range and 50% of their historic population (Cilliers et al. 2013). One of the conservation tools being used to address this issue is reintroductions, with the hope that it will help to restore Southern Ground Hornbill populations to their historic range (Cilliers et al. 2013).

Magpie Shrikes prefer open savanna woodland with short grass clumps and some bare ground (Hockey et al. 2005). Magpie Shrikes like to perch on trees or bushes from where they search the surroundings for prey (insects and other invertebrates), and when something is spotted they dive down to the ground to catch it (Hockey et al. 2005). If the habitat has too much woody cover, it could become difficult for birds that use the "perch and scan" method to spot and catch their prey. Lilac-breasted Rollers often occupy the border between woodland and grassy clearings, because they use woodland habitats for breeding and forage in the grassy clearings in between (Hockey et al. 2005). Like the Magpie Shrike, Lilac-breasted Rollers like to perch on a bush or tree where they can keep an eye out for prey on the ground, which includes insects and sometimes small vertebrates like rodents and reptiles (IUCN 2016).

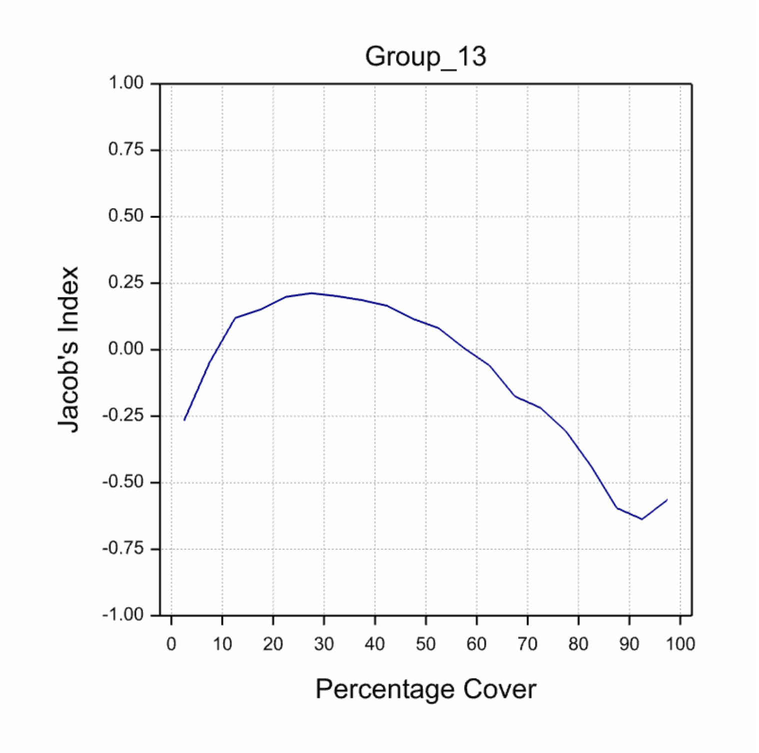

Figure 2.6 Woody cover preference plot for Group 13.

Group 11 includes species such as European Roller *Coracias garrulus*, Southern Yellow-billed Hornbill *Tockus leucomelas*, White-backed Vulture *Gyps africanus* and Bateleur *Terathopius ecaudatus*. The species in this group prefers a woody cover of 15–55% with a peak at 35% (Figure 2.7), slightly higher cover percentages than those in Group 13.

European Rollers are most commonly found in open *Vachellia* and broad-leaved woodlands with grassy clearings (Hockey et al. 2005). Southern Yellow-billed Hornbills are found in various wooded vegetation types, but they favour dry, open *Vachellia* and broad-leaved woodland with short ground cover and some open areas (Hockey et al. 2005).

White-backed Vultures prefer areas with open woodland, especially arid savanna, which includes Mopane woodland, and they avoid true forest (Hockey et al. 2005). These vultures need some woody cover as they use the taller trees for roosting and breeding (Mundy 1997). White-backed Vultures are listed as Critically Endangered globally by the International Union for Conservation of Nature (IUCN) (BirdLife International 2015). Vultures might be impacted by bush encroachment in two ways. Firstly, increased woody cover can make it difficult for vultures to locate animal carcasses, as they rely almost entirely on their eyesight to locate carcasses while scanning the ground from the air (Bamford et al. 2009). In a study done on Cape Vultures *Gyps coprotheres* by Schultz (2007) in Namibia, it was established that these vultures were in fact unable to locate carcasses in areas where the vegetation had become too thick (tree densities greater than 2600 trees per hectare). Secondly, vultures are heavy birds that need sufficient space to take off from the ground. If the vegetation of an area is too thick, vultures do not have enough space to take off and so they might avoid such areas all together, and so lose out on food, or in choosing to land they become vulnerable to ambush predators (Bamford et al. 2009). The White-backed Vultures and Cape Vultures observed in the study by Bamford et al. (2009) were hesitant to land at carcasses where the take-off angle required to clear the surrounding vegetation was greater than about 6° (for White-backed Vulture) and 4° (for Cape Vulture). Larger, heavier vultures, for example Lappet-faced Vultures *Torgos tracheliotos* might struggle even more with increased take-off angles, because of their higher "wing loading" (Mundy et al. 1992). The wing loading on a vulture that has just fed will be even higher than normal, further impacting their take-off range (Bamford et al. 2009).

The Bateleur prefers *Vachellia* savanna, Mopane woodland and miombo. It favours broad-leaved woodlands with long grass and it avoids areas that are too woody (Hockey et al. 2005). Bateleurs are listed as Near Threatened globally by the IUCN (BirdLife International 2012) and Endangered in South Africa, Lesotho and Swaziland (Brown 2015). The Tawny Eagle *Aquila rapax* is also part of Group 11. Tawny Eagles prefer open woodland and they are absent from dense forest (Hockey et al. 2005). These eagles, like Bateleurs, use trees for nesting and roosting. A study by Wichmann et al. (2004) found that there is a tree density threshold for Tawny Eagles when it comes to selecting a nesting site. Their spatially explicit model predicted decreased persistence of Tawny Eagles at high tree densities (Wichmann et al. 2004). If an area becomes too woody this could cause Tawny Eagles and Bateleur to avoid such areas. In South Africa, Lesotho and Swaziland the Tawny Eagle is listed as Endangered (Taylor et al. 2015). Tawny Eagles are very sensitive to changes in habitat and land-use transformation, which makes them largely dependent on protected areas, like national parks, for survival (Herremans and Herremans-Tonnoeyr 2000). It is possible then to argue that this makes them vulnerable to any vegetation changes, like bush encroachment, that might occur in protected areas.

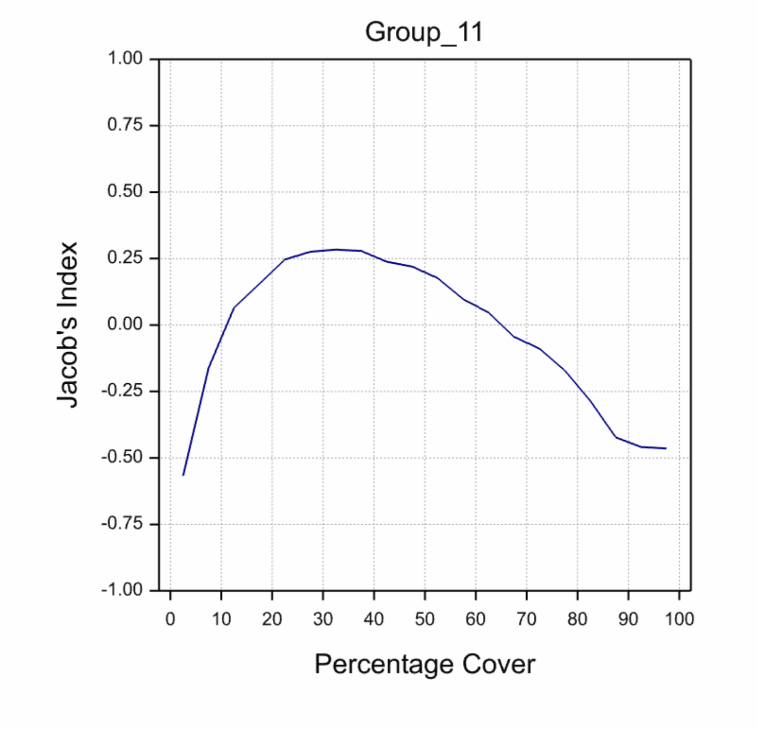

Figure 2.7 Woody cover preference for Group 11.

Group 9 contains birds like Brubru *Nilaus afer*, Bearded Woodpecker *Dendropicos namaquus*, Long-billed Crombec *Sylvietta rufescens* and White-browed Scrub-Robin *Cercotrichas leucophrys.* This group shows a preference for habitats with 20–70% woody cover (Figure 2.8). The Brubru favours tall Mopane woodland and tall *Vachellia* savanna, as well as a mosaic of broad- and fine-leaved woodland (Hockey et al. 2005). Bearded Woodpeckers prefer open woodland and savanna, including thornveld, Mopane woodland and miombo, and they avoid evergreen forests (Hockey et al. 2005). The Long-billed Crombec prefers a wide variety of wooded habitats, especially dry savanna with scattered bushes and trees and mixed-species woodlands with well-developed understoreys (Harrison 1997b). They avoid open grasslands and forest interiors (Harrison 1997b). White-browed Scrub-Robins favour *Vachellia* woodland, but they also utilize mixed-species broad-leaved woodlands (Oatley 1997c). They like habitats with dense undergrowth, but they tend to avoid closed canopy forests (Oatley 1997c)

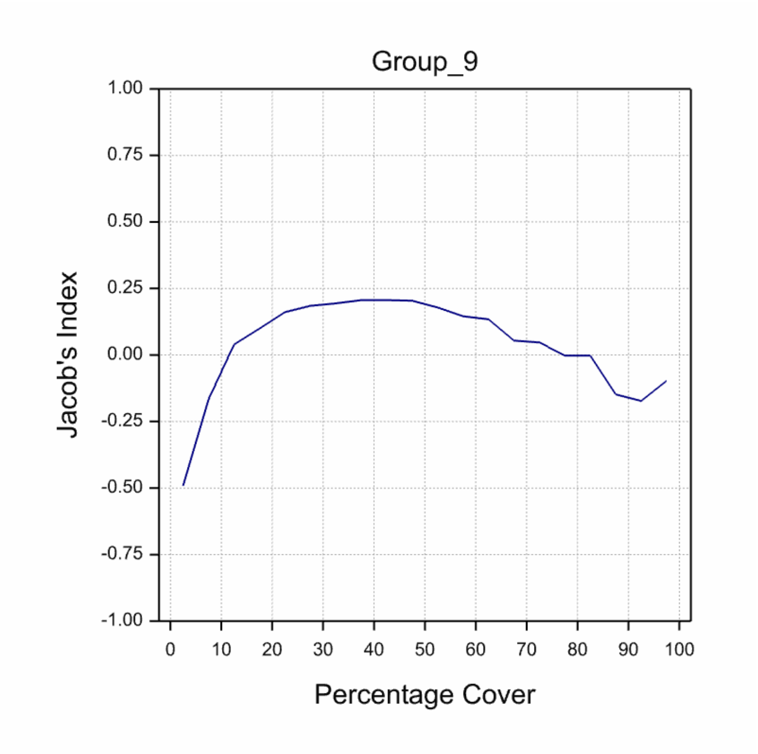

Figure 2.8 Woody cover preference for Group 9.

Group 14 contains birds such as Emerald-Spotted Wood Dove *Turtur chalcospilos*, Grey-headed Bush-Shrike *Malaconotus blanchoti*, White-throated Robin-Chat *Cossypha humeralis*, and Common Scimitarbill *Rhinopomastus cyanomelas*. This group prefers habitats with at least 40% woody cover (Figure 2.9). Emerald-spotted Wood Doves like various woodland types as well as thornveld and thickets, but they are absent from closed canopy forests (Colahan 1997).

The Grey-headed Bush-Shrike prefers a mosaic of woodland-forest habitats, which includes miombo and *Vachellia* woodlands, valley bushveld, riverine forest, and thornveld (Hockey et al. 2005). Common Scimitarbills prefer tropical and subtropical woodland, especially miombo and Mopane woodland areas (du Plessis 1997). They avoid woodlands with completely closed canopies (du Plessis 1997).

White-throated Robin-Chats favour dense thickets, thornveld, as well as *Vachellia* and broad-leaved woodlands (Hockey et al. 2005). They also do most of their foraging in the leaf litter under thickets (Hockey et al. 2005).

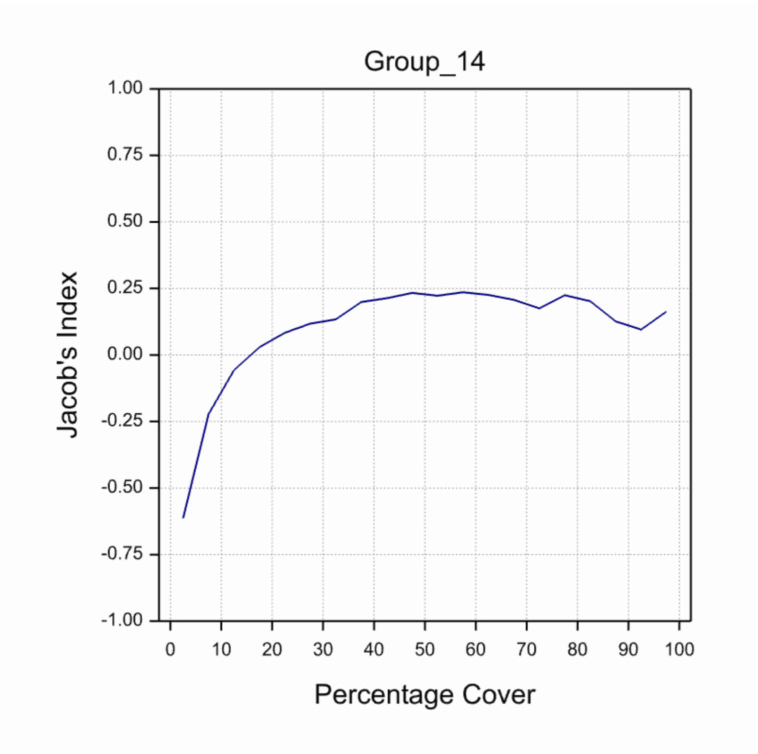

Figure 2.9 Woody cover preference for Group 14.

Group 12 contains Sombre Greenbul *Andropadus importunus*, Purple-crested Turaco *Gallirex porphyreolophus,* Cape Batis *Batis capensis* and Spectacled Weaver *Ploceus ocularis*. This group prefers habitats with more than 40% woody cover, with preference increasing as woody cover increases (Figure 2.10).

The SABAP1 vegetation analysis found that Sombre Greenbuls were most common in forests, valley bushveld, thickets and other woody vegetation (Oatley 1997b). Sombre Greenbuls, along with all the other members of the bulbul family Pycnonotidae, have shown big increases in abundance and have expanded their geographic ranges since SABAP1 (Loftie-Eaton 2014). Most of the birds in this family prefer habitats with lots of woody cover and tangled vegetation where they forage for fruits, seeds and insects (Fishpool and Tobias 2005).

Purple-crested Turacos favour moist woodland, thickets and riverine forest (Hockey et al. 2005). All members of the Musophagidae family live in savanna, woodland or forest areas (Hockey et al. 2005). If these types of habitats become more common due to bush encroachment, then turacos will benefit and likely increase in abundance.

The Cape Batis is associated with valley bushveld, dense thornveld and Afromontane forest (Johnson 1997). They are generally seen as forest birds, but they are not restricted to it and they have been observed in small forest patches, and they readily colonize or recolonize these woody habitats (Johnson 1997). The

Cape Batis forages for insects in the undergrowth, but they do make use of the forest canopy too (Johnson 1997). Spectacled Weavers prefer well-wooded habitats with dense undergrowth, such as forest edges, woodlands, riverine vegetation, wooded valleys and gardens (Hockey et al. 2005). The birds in this Group would most likely benefit from bush encroachment.

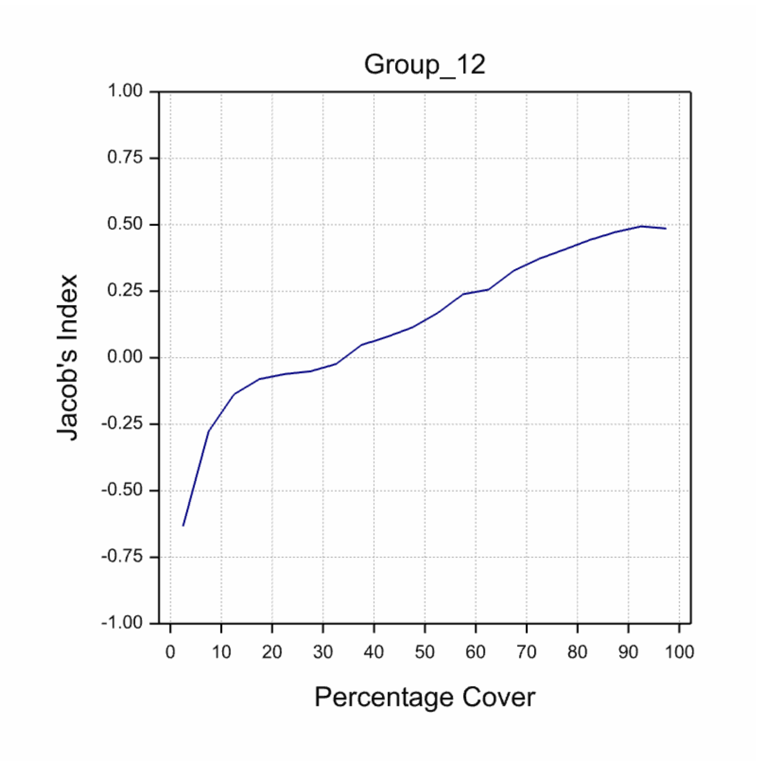

Figure 2.10 Woody cover preference for Group 12.

Group 21 contains Green Twinspot *Mandingoa nitidula,* Golden Weaver *Ploceus xanthops*, Olive Woodpecker *Dendropicos griseocephalus* and Terrestrial Brownbul *Phyllastrephus terrestris*. These birds are forest associated species, preferring closed canopy habitats. Preference for a habitat increases with an increased in woody cover percentage (Figure 2.11). The Green Twinspot is a seed-eating forest associated bird. It prefers tangled bracken-brier scrub, forest edges, and will readily make use of alien tree plantations and well-wooded gardens (Hockey et al. 2005). The Green Twinspot has expanded its range since SABAP1 (Loftie-Eaton 2014). This can probably be attributed to an increase in woody cover.

Golden Weavers are associated with rank vegetation, well-wooded savanna, and riparian woodland (Craig 1997). The Olive Woodpecker prefers Afromontane forests, but also makes use of thornveld, well-wooded gardens, and sometimes scrub vegetation (Hockey et al. 2005).

Terrestrial Brownbuls have a strong preference for forest habitats and areas with dense or tangled vegetation. The SABAP1 vegetation analysis shows its preference accurately, with reporting rates in South Africa being highest in Afromontane and coastal forests as well as valley bushveld (Oatley 1997a). They are often found in dense stands of Buckweed *Isoglossa woodii* undergrowth where they forage in the leaf litter for arthropods (Oatley 1997a). Terrestrial Brownbuls have expanded their geographic range and increased in abundance since SABAP1 (Figure 2.12) and this is most likely due to an increase in woody cover across the South African landscape (i.e. bush encroachment).

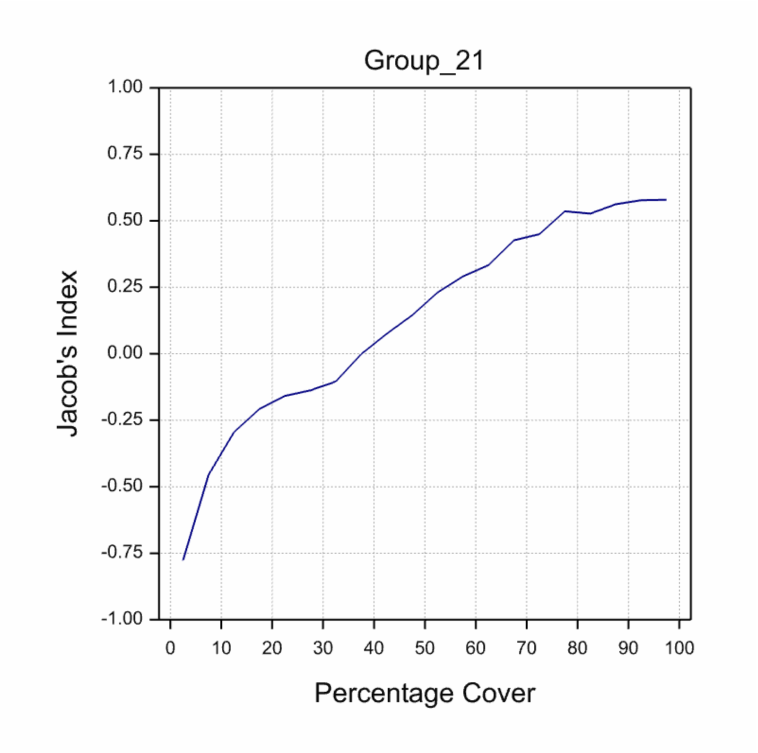

Figure 2.11 Woody cover preference for Group 21.

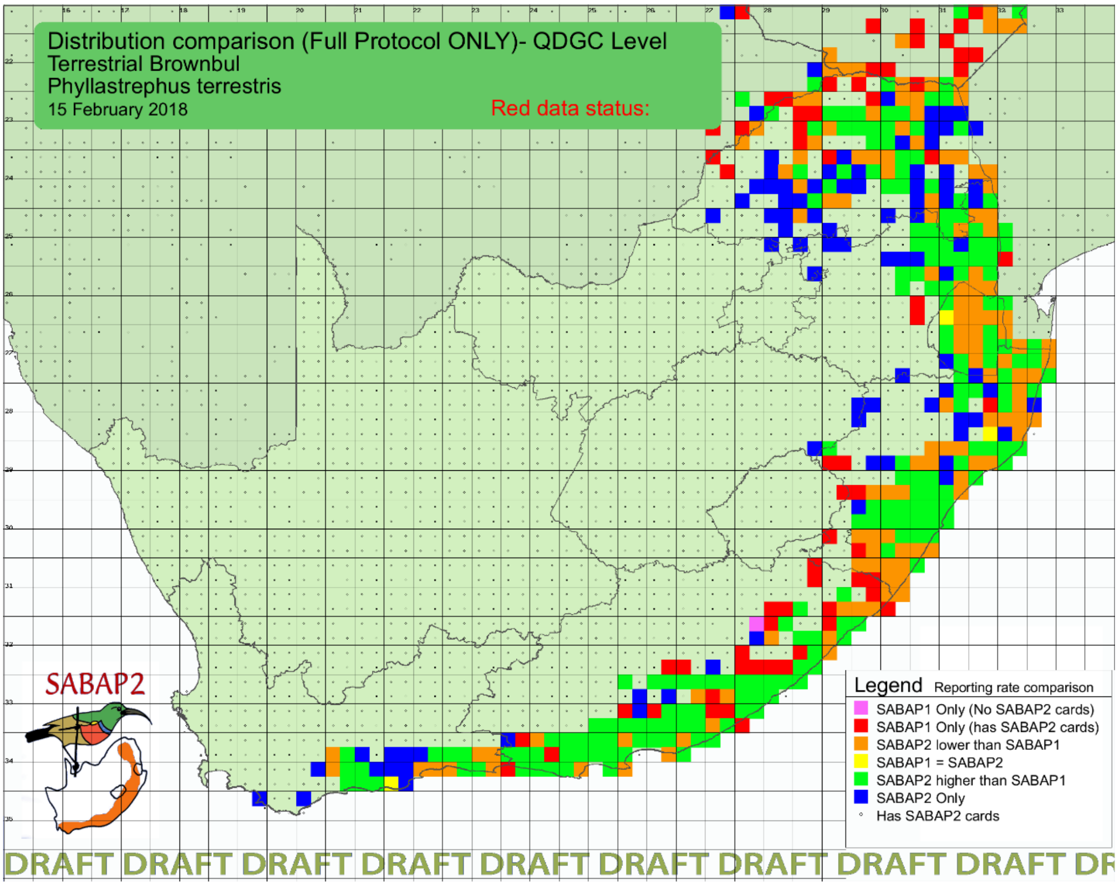

Figure 2.12 Distribution comparison between SABAP1 and 2 for Terrestrial Brownbul. Blue squares represent range extensions since SABAP1, green squares represent increased reporting rate since SABAP1, orange squares represent decreased reporting rates and red squares represent range contractions since SABAP1.

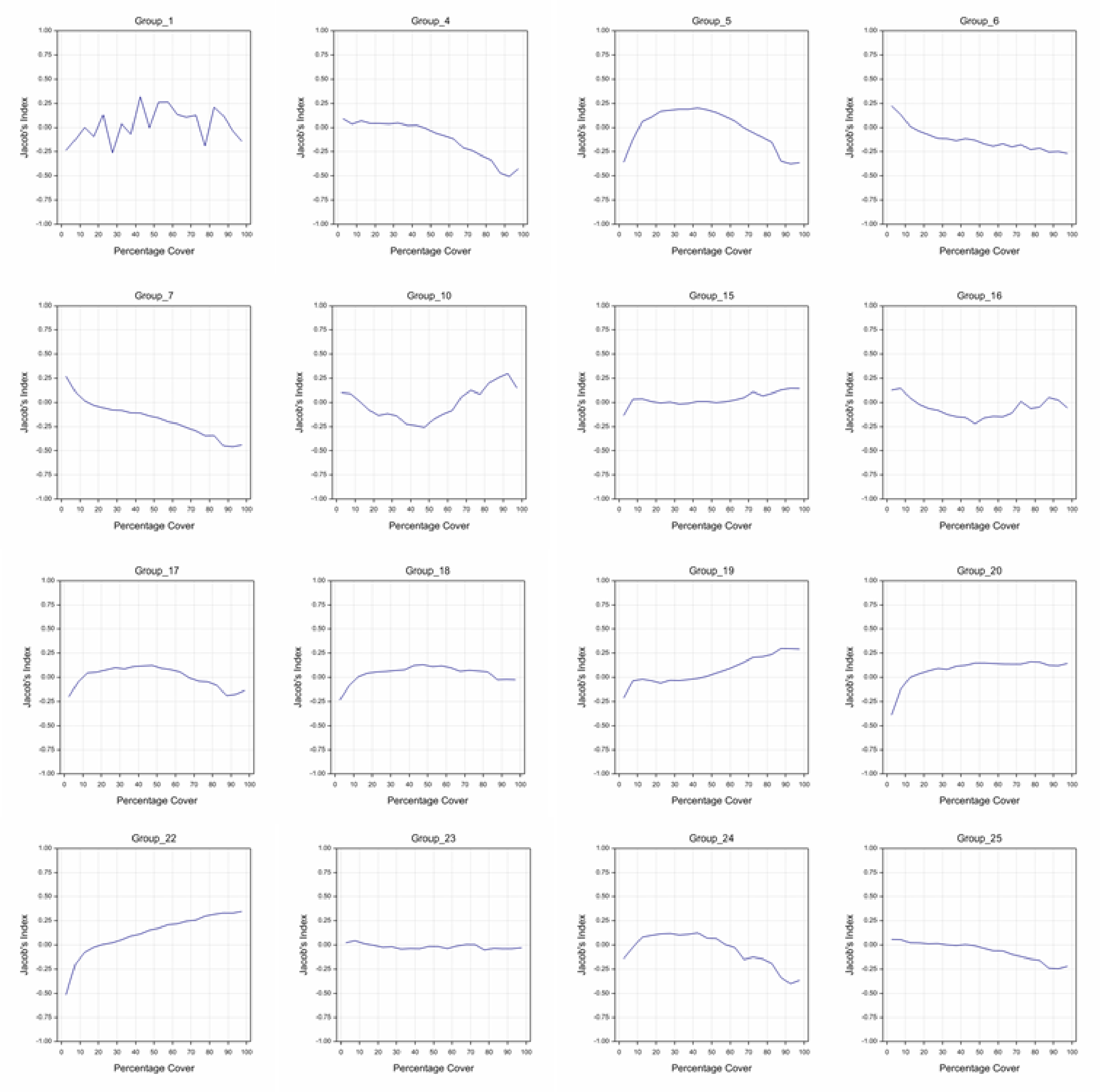

Figure 2.13 Group signatures for the remaining 16 of the 25 groups of Figure 2.2, showing the woody cover preferences of each group. The species allocated to each group by the non-hierarchical clustering algorithm are listed in Appendix 2.A. The species within a group have signatures similar to the group signature.

At this point, I have worked across the nine groups that define the arch containing the upper points in Figure 2.2. The group signatures of the remaining 16 groups (Figure 2.13) all show less strong preferences for particular woody cover classes than the nine groups considered above. I label this the interior groups. At the extreme, the signature for Group 23 is almost horizontal, indicating no preference for any woody cover class. In Figure 2.2, Group 23 lies in the middle of all the points. The group contains species such as Lanner Falcon *Falco biarmicus*, Rock Martin *Ptyonoprogne fuligula* and Common Waxbill *Estrilda astrild* (Appendix 2.A) which have habitat requirements which are independent of woody cover (Hockey et al. 2005). Group 1 consists of a single species, African Marsh Harrier *Circus ranivorus*; the occurrence of this species is determined by the presence of suitable wetlands (Hockey et al. 2005), which occur erratically in relation to woody cover, which accounts for the saw-tooth appearance of the signature for this species (Figure 2.13). Of the groups in Figure 2.13, the one which appears to have the strongest relation to woody cover is Group 5. In the non-metric multidimensional scaling plot of Figure 2.2, Group 5 is located close to Group 11 (Figure 2.7). Group 5 shares the same woody cover preference range of 15–55% as Group 11, but the signature plotted for Group 5 is flatter than for Group 11, indicating that Group 5 consists of species with less strong woody cover preferences than those in Group 11. From the perspective of selecting species which are sensitive to a narrow range of woody cover preferences, none of the species belonging to any of the interior groups (Figures 2.2 and 2.13) is worth further consideration.

Final Discussion and Conclusions

Firstly, I assess the utility of this exploratory data analysis algorithm. The most important result is that there were no surprises. The "signatures" of species coincided with qualitative expectations; however, they do provide, for the first time, solid quantitative information of the woody cover preferences of bird species. It is thus clear that the algorithm does produce meaningful results, which are readily interpreted. As an example of an application of Tukey's (1977) philosophy of exploratory data analysis, the approach is successful. Scott (2018) used a variation of this algorithm to generate signatures for bird species along an altitudinal gradient in KwaZulu-Natal. In her application of the algorithm, 100 altitudinal data points were available per pentad, instead of the 400 woody cover data points used in this application. The bird signatures calculated by Scott (2018) provided excellent insights into distribution preferences of bird species in relation to altitude. Her results provide valuable confirmation that the algorithm used in this analysis has broader applications than only woody cover. The essential requirement is for data on an explanatory variable on a considerably finer grid scale than the pentad scale of the bird data.

Perhaps the biggest surprise coming out of the entire analysis was the way in which the groups located along the "arch" of the non-metric multidimensional scaling (Figure 2.2) were the key groups of most interest, and that the species that were members of the interior groups were identified as those with habitat needs that were not related, or less related, to the woody cover classes. This approach to identifying the most interesting species in relation to woody cover had not been anticipated prior to the implementation of the algorithm.

The woody cover data used in the chapter, derived from LiDAR systems, has been a crucial component of its success. This application has not made use of the full potential of the explanatory information that is available from this source, which can also be adapted and used to distinguish different tree species from one another. Cho et al. (2012) found that using spectral and LiDAR systems was an effective way to map tree species in the Lowveld of South Africa. Detecting and mapping tree species such as Sicklebush *Dichrostachys cinerea* and Red Bushwillow *Combretum apiculatum* which are often associated with bush encroached areas (Dalle et al. 2006, Mamashela et al., 2008) might enable us to apply the algorithm devised in this chapter to find the bird species most closely associated with this form of bush encroachment. The detailed mapping of Sicklebush and Red Bushwillow made possible from the LiDAR systems is also a useful land management tool and can help managers to control species. Cho et al. (2012) found a widespread distribution of Sicklebush and Red Bushwillow in their study area which comprised the Sabi Sands Private Nature Reserve and the communal lands adjacent to the Kruger National Park in the Lowveld region of north-eastern South Africa. Mapping and detecting the various tree species of savannas is an important element in the management and conservation of savanna ecosystems. The success of management strategies to control the bush encroachment caused by these two species, as evaluated by its impact on key bird species, can be evaluated by this chapter's algorithm.

The results presented above are consistent with the findings of Sirami et al. (2009); they found that bird species composition showed a high turnover along the gradient of open grassland to forest and they found that bird species richness peaked at intermediate levels of woody cover. Similar results have been found for other taxa, showing highest species richness at intermediate levels of bush encroachment, these taxa include: reptiles (Wasiolka 2003), carnivores (Blaum et al. 2007) and rodents (Blaum et al. 2006). Widespread bush encroachment is likely to lead to the loss of certain species and a decline in overall bird species richness at the landscape scale (Sirami et al. 2009). They also determined that birds showed a greater response to changes in vegetation structure instead of vegetation species composition. For example, the bird species found in shrublands dominated by Black Thorn *Senegalia mellifera* were similar to the birds found in shrublands dominated by Camphor Bush *Tarchonanthus camphoratus* (Sirami et al. 2009). Thus, the approach considered here, of using a simple single measure, woody cover, rather than an analysis based on tree species communities, is likely to yield satisfactory results. Bush encroachment probably has a bigger effect on bird species diversity when the initial habitat is grassland rather than open woodland.

The woody cover preference plots can help us to determine where, across a landscape, certain species are most likely to occur. And, importantly, we will be able to tell how much of the available habitat in an area is still suitable for a species. For example, one can examine the woody cover map for an area (for example a national park) in South Africa and then use the individual species woody cover preference plots to determine how much of the habitat in the selected area is still suitable for certain keystone or sensitive species. Following that, appropriate land management practices can be implemented in target areas. For example, the overall woody cover preference of Southern Ground Hornbill, which is in Group 13 (Figure 2.6), is in the range 15–55%, with 20–40% being the peak preference. Thus, in an area where Southern Ground Hornbills currently occur, the population can be strengthened by maintaining woody cover in this target range. This management strategy would also benefit all the remaining species in Group 13.

The density of woody plants such as trees and shrubs has an impact on the bird species present in an area, because habitat availability is impacted. Birds are not the only species affected by bush encroachment. This vegetation dynamic also severely compromises the availability of grazing resources, which is valuable for livestock populations (and other grazing herbivores) as well as for the many people in South Africa whose livelihoods depend livestock farming/production (Wigley et al. 2009).

From the biodiversity perspective, this research will make a substantial contribution to conservation management and policy development. The reason for this is that changes in woody cover (bush encroachment and bush thickening) will be shown to be the single key factor underpinning the range expansion of many bird species, and the range contractions of many others, some of which are in IUCN threat categories. Thus, instead of undertaking research into the declines (and increases) of each individual species, which would be resource intensive, one single factor like bush encroachment is likely to be common to a large number of species. So, in place of many individual species action plans, a single action can be implemented.

The algorithm developed in this chapter opens up opportunities for the quantitative study of bush encroachment. This is hinted at by Figure 2.12, which illustrated how the distribution of the Terrestrial Bulbul (Group 21) had changed over the quarter-century between the first and second bird atlas projects. A hypothesis to be tested is that all the species of Group 21 will show similar range changes, and that the underlying pattern will be an association with areas where woody cover has increased above 50% (Figure 2.11). The prediction is that the species from this group will have increased in range and abundance (as measured by reporting rate) between SABAP1 and 2. In contrast, the species in Group 11 and Group 13 (Figures 2.6 and 2.7) are predicted to show more complex patterns of range change than those of Group 21. For Group 11 (Figure 2.7), the peak preference was at 35% woody cover, with a range of 15–55%. The predicted range change for the species in this group would be a shift in distribution: (1) species in this group would expanding into areas where bush encroachment reaches 15%; (2) they would increase in abundance (reporting rate) as bush encroachment increases to 35%; (3) they would decrease in abundance as bush encroachment increased beyond 35%; (4) they would go locally extinct in areas where bush encroachment increased above 55%. Species in Group 13 (Figure 2.6) are predicted to show a similar pattern, with slightly different values for the cut offs. Once good quantitative data showing trends in woody cover, derived from LiDAR, are available, these predictions could be tested. The range-change map for one species of Group 13, the Magpie Shrike (Figure 2.14), provides qualitative support for this hypothesis of a range shift. The map hints at a westward shift in distribution, with reduced reporting rates, and some local extinctions, in the east, and with range expansion and increased reporting rates in the west of the range.

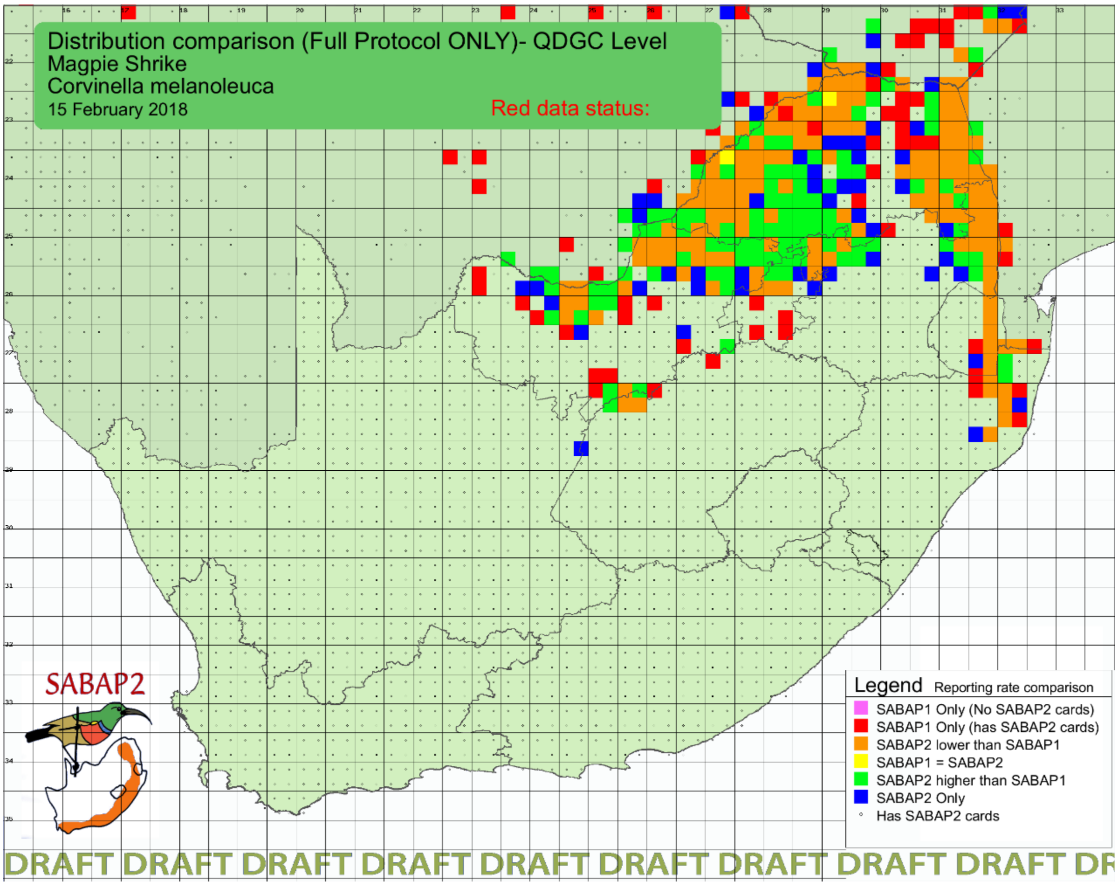

Figure 2.14 Distribution comparison between SABAP1 and 2 for Magpie Shrike. Blue squares represent range extensions since SABAP1, green squares represent increased reporting rate since SABAP1, orange squares represent decreased reporting rates and red squares represent range contractions since SABAP1.

The main purpose of this chapter has been to establish a successful algorithm for quantifying the relationship between woody cover measurements, as derived by LiDAR systems, and bird abundance, as measured through the citizen science dataset generated by the bird atlas. In Chapter 3, I apply the same approach in another region within the Savanna Biome, the Kruger National Park. First of all, it will be important to assess whether the algorithm works as well there as it did in this study transect. If so, the second objective of Chapter 3 will be to attempt to identify a set of bird species which are likely to be of value in monitoring bush encroachment (and the management thereof) using the bird atlas data.

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APPENDIX 2.A Bird species in each of the 25 groups defined by the non-hierarchical clustering algorithm (see text) for the study transect consisting of the three degree cells, 2528, 2529 and 2530, in northern South Africa.

Species in group	Group number
Group 1: one species	
African Marsh-Harrier	1
Group 2: 22 species	
Great Crested Grebe	2
Yellow-billed Egret	2
Greater Flamingo	2
Spur-winged Goose	2
Cape Shoveler	2
Maccoa Duck	2
White-backed Duck	2
Montagu's Harrier	2
Red-knobbed Coot	2
African Snipe	2
Whiskered Tern	2
Marsh Owl	2
Spike-heeled Lark	2
Red-capped Lark	2
South African Cliff-Swallow	2
Banded Martin	2
Ant-eating Chat	2
Cloud Cisticola	2
Pied Starling	2
Long-tailed Widowbird	2
Eastern Clapper Lark	2
Eastern Long-billed Lark	2
Group 3: 33 species	
Little Grebe	3
Southern Bald Ibis	3
Glossy Ibis	3
South African Shelduck	3
Yellow-billed Duck	3
Red-billed Teal	3
Cape Teal	3
Hottentot Teal	3
Southern Pochard	3
Greater Kestrel	3
Lesser Kestrel	3
Orange River Francolin	3
African Rail	3
African Purple Swamphen	3

Species in group	Group number
Blue Crane	3
White-bellied Korhaan	3
Blacksmith Lapwing	3
Marsh Sandpiper	3
White-winged Tern	3
Melodious Lark	3
Fawn-coloured Lark	3
Chestnut-backed Sparrowlark	3
Cape Crow	3
Mountain Wheatear	3
Capped Wheatear	3
Desert Cisticola	3
Buffy Pipit	3
Cape Longclaw	3
Cape Sparrow	3
Yellow-crowned Bishop	3
African Quailfinch	3
Black-throated Canary	3
Northern Black Korhaan	3
Group 4: 21 species	
Purple Heron	4
Great Egret	4
Little Egret	4
Black Heron	4
Black-chested Snake-Eagle	4
Coqui Francolin	4
Harlequin Quail	4
Kittlitz's Plover	4
Three-banded Plover	4
Common Greenshank	4
Wood Sandpiper	4
Black-winged Stilt	4
Laughing Dove	4
Rufous-cheeked Nightjar	4
Common Swift	4
Pied Crow	4
Icterine Warbler	4
Lesser Grey Shrike	4
Wattled Starling	4
Red-billed Quelea	4
Rock Dove	4
Group 5: 15 species	
African Openbill	5

Species in group	**Group number**
Shikra	5
Crested Francolin	5
Senegal Lapwing	5
Grey Go-away-bird	5
Levaillant's Cuckoo	5
Jacobin Cuckoo	5
Southern White-faced Scops-Owl	5
African Grey Hornbill	5
Grey-backed Camaroptera	5
Rattling Cisticola	5
Pale Flycatcher	5
Brown-crowned Tchagra	5
Blue Waxbill	5
Purple Indigobird	5
Group 6: 16 species	
Reed Cormorant	6
Little Bittern	6
Egyptian Goose	6
Osprey	6
Red-winged Francolin	6
Common Quail	6
Red-chested Flufftail	6
Common Moorhen	6
White-throated Swallow	6
Wing-snapping Cisticola	6
Levaillant's Cisticola	6
Cape Wagtail	6
Plain-backed Pipit	6
Common Fiscal	6
Bokmakierie	6
Orange-breasted Waxbill	6
Group 7: 24 species	
Grey Heron	7
Black-headed Heron	7
Cattle Egret	7
Squacco Heron	7
African Sacred Ibis	7
African Spoonbill	7
Fulvous Duck	7
Amur Falcon	7
Black-shouldered Kite	7
Swainson's Spurfowl	7
Crowned Lapwing	7

Species in group	**Group number**
Little Stint	7
Ruff	7
Pied Avocet	7
Grey-headed Gull	7
Speckled Pigeon	7
Rufous-naped Lark	7
Brown-throated Martin	7
Zitting Cisticola	7
African Pipit	7
Common Myna	7
Southern Masked-Weaver	7
Southern Red Bishop	7
Red-headed Finch	7
Group 8: 15 species	
European Honey-Buzzard	8
Temminck's Courser	8
Black-winged Pratincole	8
Namaqua Dove	8
Purple Roller	8
Sabota Lark	8
Pearl-breasted Swallow	8
Red-breasted Swallow	8
Kalahari Scrub-Robin	8
Barred Wren-Warbler	8
Black-chested Prinia	8
Marico Flycatcher	8
Great Sparrow	8
Scaly-feathered Finch	8
Yellow Canary	8
Group 9: 21 species	
Black Stork	9
African Hawk-Eagle	9
Martial Eagle	9
Lizard Buzzard	9
Brown Snake-Eagle	9
Water Thick-knee	9
Square-tailed Nightjar	9
Woodland Kingfisher	9
Bearded Woodpecker	9
Grey Penduline-Tit	9
Yellow-bellied Greenbul	9
White-browed Scrub-Robin	9
Long-billed Crombec	9

Species in group	**Group number**
Chinspot Batis	9
Bushveld Pipit	9
Brubru	9
Yellow-throated Petronia	9
Lesser Masked-Weaver	9
Red-headed Weaver	9
Jameson's Firefinch	9
Golden-breasted Bunting	9
Group 10: two species	
Black-winged Lapwing	10
Cape Canary	10
Group 11: 25 species	
Marabou Stork	11
Saddle-billed Stork	11
Woolly-necked Stork	11
White-backed Vulture	11
White-headed Vulture	11
Hooded Vulture	11
Tawny Eagle	11
Wahlberg's Eagle	11
Bateleur	11
Dark Chanting Goshawk	11
Bronze-winged Courser	11
Brown-headed Parrot	11
African Cuckoo	11
African Scops-Owl	11
Verreaux's Eagle-Owl	11
European Roller	11
Southern Yellow-billed Hornbill	11
Bennett's Woodpecker	11
Eurasian Golden Oriole	11
Yellow-bellied Eremomela	11
Stierling's Wren-Warbler	11
Southern White-crowned Shrike	11
Greater Blue-eared Starling	11
Red-billed Oxpecker	11
Red-billed Hornbill	11
Group 12: 25 species	
Long-crested Eagle	12
African Crowned Eagle	12
African Goshawk	12
Red-necked Spurfowl	12
African Olive-Pigeon	12

Species in group	**Group number**
Purple-crested Turaco	12
African Wood-Owl	12
Crowned Hornbill	12
Black Saw-wing	12
Grey Cuckooshrike	12
Sombre Greenbul	12
Chorister Robin-Chat	12
Bar-throated Apalis	12
Green-backed Camaroptera	12
African Dusky Flycatcher	12
Ashy Flycatcher	12
Cape Batis	12
Olive Bush-Shrike	12
Gorgeous Bush-Shrike	12
Eastern Nicator	12
Spectacled Weaver	12
Swee Waxbill	12
African Firefinch	12
Dusky Indigobird	12
Knysna Turaco	12
Group 13: 24 species	
Yellow-billed Stork	13
Lappet-faced Vulture	13
Lesser Spotted Eagle	13
Gabar Goshawk	13
Red-crested Korhaan	13
Black-bellied Bustard	13
Double-banded Sandgrouse	13
Great Spotted Cuckoo	13
Pearl-spotted Owlet	13
Southern Carmine Bee-eater	13
Lilac-breasted Roller	13
Southern Ground-Hornbill	13
Ashy Tit	13
Southern Pied Babbler	13
Chestnut-vented Tit-Babbler	13
Magpie Shrike	13
Burchell's Starling	13
Marico Sunbird	13
Red-billed Buffalo-Weaver	13
Green-winged Pytilia	13
Violet-eared Waxbill	13
Black-faced Waxbill	13

Species in group	Group number
Shaft-tailed Whydah	13
Village Indigobird	13
Group 14: 12 species	
Emerald-spotted Wood-Dove	14
Common Scimitarbill	14
Black Cuckooshrike	14
White-throated Robin-Chat	14
Red-faced Cisticola	14
Grey Tit-Flycatcher	14
Orange-breasted Bush-Shrike	14
Grey-headed Bush-Shrike	14
White-crested Helmet-Shrike	14
Retz's Helmet-Shrike	14
Purple-banded Sunbird	14
Scarlet-chested Sunbird	14
Group 15: 15 species	
African Black Duck	15
Jackal Buzzard	15
Shelley's Francolin	15
Red-eyed Dove	15
African Black Swift	15
Speckled Mousebird	15
Giant Kingfisher	15
Red-throated Wryneck	15
Cape Rock-Thrush	15
Buff-streaked Chat	15
Little Rush-Warbler	15
Cape Grassbird	15
Long-billed Pipit	15
Red-winged Starling	15
Malachite Sunbird	15
Group 16: four species	
Alpine Swift	16
African Stonechat	16
Cape Weaver	16
Yellow Bishop	16
Group 17: 20 species	
Green-backed Heron	17
Cape Vulture	17
Verreaux's Eagle	17
Red-faced Mousebird	17
Pied Kingfisher	17
European Bee-eater	17

Species in group	**Group number**
Green Wood-Hoopoe	17
Crested Barbet	17
Greater Honeyguide	17
Common House-Martin	17
Arrow-marked Babbler	17
Mocking Cliff-Chat	17
Willow Warbler	17
Green-capped Eremomela	17
Neddicky	17
Spotted Flycatcher	17
Fairy Flycatcher	17
Cape Glossy Starling	17
Cinnamon-breasted Bunting	17
Cape Bunting	17
Group 18: 16 species	
Black-crowned Night-Heron	18
Yellow-billed Kite	18
African Fish-Eagle	18
African Harrier-Hawk	18
Black Crake	18
African Jacana	18
Red-chested Cuckoo	18
African Palm-Swift	18
White-fronted Bee-eater	18
Little Bee-eater	18
African Hoopoe	18
Lesser Striped Swallow	18
Fork-tailed Drongo	18
Groundscraper Thrush	18
Cut-throat Finch	18
Southern Grey-headed Sparrow	18
Group 19: 14 species	
Peregrine Falcon	19
African Cuckoo Hawk	19
Black Sparrowhawk	19
Half-collared Kingfisher	19
Brown-backed Honeybird	19
Dark-capped Bulbul	19
Cape Robin-Chat	19
Broad-tailed Warbler	19
Wailing Cisticola	19
Dark-capped Yellow Warbler	19
Red-collared Widowbird	19

Species in group	**Group number**
Streaky-headed Seedeater	19
Drakensberg Prinia	19
Olive Thrush	19
Group 20: 27 species	
Little Sparrowhawk	20
Natal Spurfowl	20
African Finfoot	20
African Green-Pigeon	20
Black Cuckoo	20
Klaas's Cuckoo	20
Spotted Eagle-Owl	20
Fiery-necked Nightjar	20
Freckled Nightjar	20
African Pygmy-Kingfisher	20
Brown-hooded Kingfisher	20
Black-collared Barbet	20
Yellow-fronted Tinkerbird	20
Lesser Honeyguide	20
Cardinal Woodpecker	20
Grey-rumped Swallow	20
Southern Black Tit	20
Marsh Warbler	20
Croaking Cisticola	20
Southern Black Flycatcher	20
African Paradise-Flycatcher	20
Black-crowned Tchagra	20
Violet-backed Starling	20
Gurney's Sugarbird	20
White-bellied Sunbird	20
Village Weaver	20
Burchell's Coucal	20
Group 21: 20 species	
Tambourine Dove	21
African Emerald Cuckoo	21
Narina Trogon	21
Trumpeter Hornbill	21
Yellow-rumped Tinkerbird	21
Scaly-throated Honeyguide	21
Olive Woodpecker	21
Square-tailed Drongo	21
Terrestrial Brownbul	21
Red-capped Robin-Chat	21
Blue-mantled Crested-Flycatcher	21

Species in group	**Group number**
Mountain Wagtail	21
Black-bellied Starling	21
Southern Double-collared Sunbird	21
Olive Sunbird	21
Collared Sunbird	21
Golden Weaver	21
Red-backed Mannikin	21
Green Twinspot	21
Forest Canary	21
Group 22: 23 species	
Eurasian Hobby	22
Golden-tailed Woodpecker	22
Wire-tailed Swallow	22
Black-headed Oriole	22
White-necked Raven	22
Kurrichane Thrush	22
White-browed Robin-Chat	22
Bearded Scrub-Robin	22
Yellow-breasted Apalis	22
Lazy Cisticola	22
Tawny-flanked Prinia	22
African Pied Wagtail	22
Striped Pipit	22
Yellow-throated Longclaw	22
Southern Boubou	22
Black-backed Puffback	22
Greater Double-collared Sunbird	22
Amethyst Sunbird	22
Thick-billed Weaver	22
Bronze Mannikin	22
Yellow-fronted Canary	22
Brimstone Canary	22
Cape White-eye	22
Group 23: 14 species	
White Stork	23
Hadeda Ibis	23
Secretarybird	23
Lanner Falcon	23
Rock Kestrel	23
Steppe Buzzard	23
Rock Martin	23
Familiar Chat	23
Great Reed-Warbler	23

Species in group	**Group number**
African Reed-Warbler	23
Fan-tailed Widowbird	23
Common Waxbill	23
Mallard Duck	23
Karoo Thrush	23
Group 24: 16 species	
Goliath Heron	24
Abdim's Stork	24
White-faced Duck	24
Striped Kingfisher	24
Acacia Pied Barbet	24
Monotonous Lark	24
Flappet Lark	24
Sand Martin	24
Garden Warbler	24
Burnt-necked Eremomela	24
Sedge Warbler	24
Red-backed Shrike	24
Crimson-breasted Shrike	24
White-browed Sparrow-Weaver	24
Red-billed Firefinch	24
Long-tailed Paradise-Whydah	24
Group 25: 26 species	
Common Ostrich	25
White-breasted Cormorant	25
African Darter	25
Hamerkop	25
Comb Duck	25
Ovambo Sparrowhawk	25
Helmeted Guineafowl	25
Kurrichane Buttonquail	25
African Wattled Lapwing	25
Common Sandpiper	25
Spotted Thick-knee	25
Cape Turtle-Dove	25
Diderick Cuckoo	25
Barn Owl	25
White-rumped Swift	25
Horus Swift	25
Little Swift	25
Malachite Kingfisher	25
Barn Swallow	25
Greater Striped Swallow	25

Species in group	**Group number**
Lesser Swamp-Warbler	25
Fiscal Flycatcher	25
House Sparrow	25
White-winged Widowbird	25
Pin-tailed Whydah	25
Cuckoo Finch	25

CHAPTER 3

The Relationship Between Woody Cover and Bird Distributions in the Kruger National Park

Introduction

The density of woody cover at a location within the Savanna Biome impacts the bird species which are recorded there (Skowno and Bond 2003; Sirami et al. 2009; Eldridge et al. 2011, Chapter 2). Examples from the extremes of the continuum of woody density are selected from the above-mentioned publications and from Harrison et al. (1997a, 1997b). Some species prefer sparse woody cover with mostly grass and clearings between the trees and shrubs. This includes species such as Dusky Lark *Pinarocorys nigricans*, Secretarybird *Sagittarius serpentarius*, Southern Ground Hornbill *Bucorvus leadbeateri*, Southern Fiscal *Lanius collaris* and Lilac-breasted Roller *Coracias caudatus* (Harrison et al. 1997a, 1997b). Other bird species prefer woody cover to be almost continuous, with little grassy cover, the interface between "savanna woodland" and "forest". This includes species such as Chinspot Batis *Batis molitor*, Black-headed Oriole *Oriolus larvatus*, most of the bulbuls (Family Pycnonotidae), Green-backed Camaroptera *Camaroptera brachyuran* and Yellow-breasted Apalis *Apalis flavida* (Harrison et al. 1997a, 1997b).

Apart from the results presented in Chapter 2, there has been no quantitative analysis of the relationship between woody cover and the preference shown by bird species to certain woody cover densities, making use of bird atlas data such as that collected as part of the Second Southern African Bird Atlas Project (SABAP2) (Underhill et al. 2017). Previous descriptions of the relationship have been qualitative, using words such as "sparse", "moderate", "thick" to refer to woody cover, as expressed in Harrison et al. (1997a, 1997b), Hockey et al. (2005) and Taylor et al. (2015), for example.

In this chapter, I make use of the algorithm devised in Chapter 2, and apply it to the bird species of the Kruger National Park (KNP). The primary goals are to gain further experience with the method, and to explore its capabilities and practical uses, for example in monitoring not only birds but also woody cover. The planned outcome is to explore the possibility of undertaking a selection of candidate bird species which are potentially the most sensitive to changes in woody cover. For monitoring purposes, it would be valuable to select a set of species along the woody density continuum which could be used as indicator species of changes in woody cover. The first step, therefore, is to identify those species which have distributions that are not related to woody cover density and exclude them from further analysis. I anticipate that many of the waterbirds would fall into this category. Then, for the species which are related to woody cover density, I describe the relationship between bird abundance and woody cover density. A selection of these species can become the key indicator species for monitoring as part of land management to understand how changing woody cover densities are impacting bird species distributions. Changes in woody cover in the KNP can be a result of the impacts of climate change, African Elephants *Loxodonta africana*, drought, bush encroachment, and a combination of these, and other, factors. As the duration of the bird atlas project increases, so the data collected by the citizen scientists participating in the project can be used as a rapid assessment approach to monitoring changes in woody cover in the Kruger National Park.

Study Area

General introduction to the Kruger National Park

The KNP, located in the north-eastern corner of South Africa, was established as a government reserve in 1898 and became South Africa's first national park in 1926 (Figure 3.1) (SANParks 2016). It was first established to control over-hunting and to protect the dwindling number of herbivores in the Lowveld (Stevenson-Hamilton 1993). Today, KNP is nearly two million hectares in size (19,485 km^2). It is a national conservation icon of South Africa and considered to be a safe haven for many fauna and flora. KNP is home to approximately 2000 species of plant, 53 fish, 34 amphibians, 118 reptiles, 517 birds and 147 mammal species (SANParks 2016).

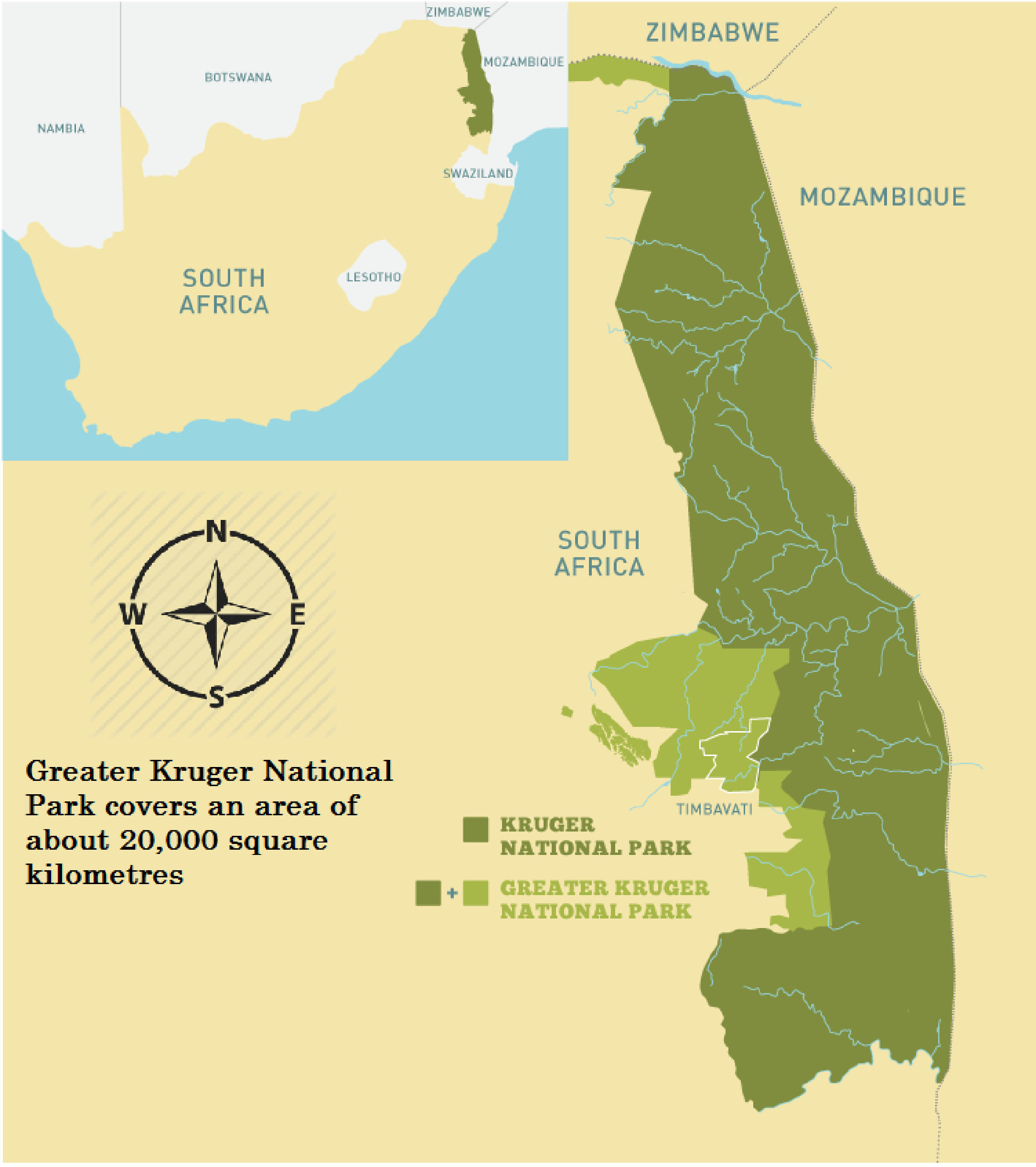

Figure 3.1 Location of Kruger National Park (PBS Nature 2012).

KNP is about 360 km long from north to south, and about 65 km wide on average, from west to east. Its widest point is 90 km (Paynter and Nussey 1986). The park is bordered by the Limpopo River in the north and the Crocodile River in the south, forming natural park boundaries. Several other rivers run through the park from west to east, including the Sabie, Olifants, Letaba, and Luvuvhu Rivers. The Lebombo Mountains lie on the eastern park boundary with Mozambique and to the west the KNP is fringed with many other private nature reserves (forming part of the Greater Kruger National Park) and local communities, villages and towns. The park's altitude ranges from 200m to 800m. The highest point is Khandzalive Hill in the south-west of the park near the Berg-en-Dal rest camp (Paynter and Nussey 1986).

The Lowveld, and consequently the KNP, has a subtropical climate. Subtropical climates are characterised by warm, humid summers and mild, dry winters. Summer temperatures can rise above 38°C. The rainy season starts around November and lasts until May. The driest period is September and October (SANParks 2016).

Vegetation in the Kruger National Park

Broadly, the northern half of KNP, north of the Olifants River is dominated mainly by Mopane *Colophospermum mopane* savanna and woodland (SANParks 2016). South of the Olifants River the habitats are mainly thornveld (dominated by *Vachellia* species). There are 336 tree species in the park (SANParks 2016). A brief description of each of the main habitat and vegetation units follows. Information is drawn primarily from Gertenbach (1983) and Mucina and Rutherford (2006):

Sandveld (Figure 3.2): located in the north of the park, this area is characterized by dramatic sandstone ridges and sandy soils. The vegetation in this area is very diverse and Baobabs *Adansonia digitata* are common.

Wooded savanna on shale (Figure 3.2): This habitat unit is located in the north-west of the KNP near Punda Maria rest camp. It is characterized by mixed stands of Knobthorn *Senegalia nigrescens*, Marula *Sclerocarya birrea* and Red Bushwillow *Combretum apiculatum* as well as thorn thickets. Bushwillow tends to form thick scrub in places (Rushworth pers. comm.). This area has good grazing, which attracts a host of herbivores. Leadwood *Combretum imberbe* trees grow along the drainage lines.

Mopane-dominated woodland on mixed soils (Figure 3.2): found in the north-west around Punda Maria rest camp. It is dominated by Mopane (tree and shrub form) and Bushwillow species. This area is also characterized by low rolling hills. This habitat is favoured by Elephants.

Open savanna grassland with stunted mopane (Figure 3.2): found along the eastern half of the Kruger. It is classified as open sweetveld grassland, not dominated by woodland, with the soil base being that of basalt. In general, the game carrying capacity in this area is low due to low rainfall and poor soils.

Mopane-dominated woodlands on granite (Figure 3.2): found along the western half of the Kruger. The Mopane trees and scrub occur here with a mix of

Bushwillow and *Vachellia* species. The grasses that occur here are classified as sourveld.

Lebombo (Figure 3.2): The Lebombo mountains or hills form the eastern boundary of the KNP. The underlying geology is comprised of rhyolite igneous rock. The vegetation on the hill crests are dominated by *Euphorbia* species and succulents like Aloes. Woodland and riverine forest are found in the valleys and gorges between the hills.

Mixed woodland with sweetveld (Figure 3.2): patches of this vegetation zone are located in the south-west. It is characterized by Knobthorn and Marula woodlands, which can be quite dense in places, interspersed with pockets of grassland.

Olifants rugged veld (Figure 3.2): this type of veld is found north-east of Satara rest camp (central Kruger), this area is defined by coarse stony soils with lots of black rock, mixed thornveld and woodlands occur here.

Mixed thorn and Marula woodlands on granite (Figure 3.2): located in the south-west of the Kruger, this vegetation zone is defined by low, rolling hills with Bushwillows, lots of Marula tree and *Vachellia* spp.

Open savanna grassland on basalt (Figure 3.2): this vegetation zone is found in the south-east of KNP. It is characterized by open plains with relatively high quality grazing. Large herds of grazing herbivores can be found in this area.

Pretoriuskop sourveld (Figure 3.2): located in the south of KNP around Pretoriuskop rest camp. It is defined by large, bare granite domes and woodlands dominated by Silver Cluster Leaf *Terminalia sericea* as well as Sickle Bush *Dichrostachys cinerea*. This area also receives more rain than the rest of KNP.

Malelane mountain bushveld (Figure 3.2): found in the south-western most corner of the park, this is also a high rainfall area. It is characterized by granite koppies (hills) and mixed Knobthorn woodland and sweetveld grasses.

Mixed woodland and thorn thickets (Figure 3.2): found in the south in the areas around the Crocodile and Sabie Rivers. The vegetation in this unit can be very dense in places.

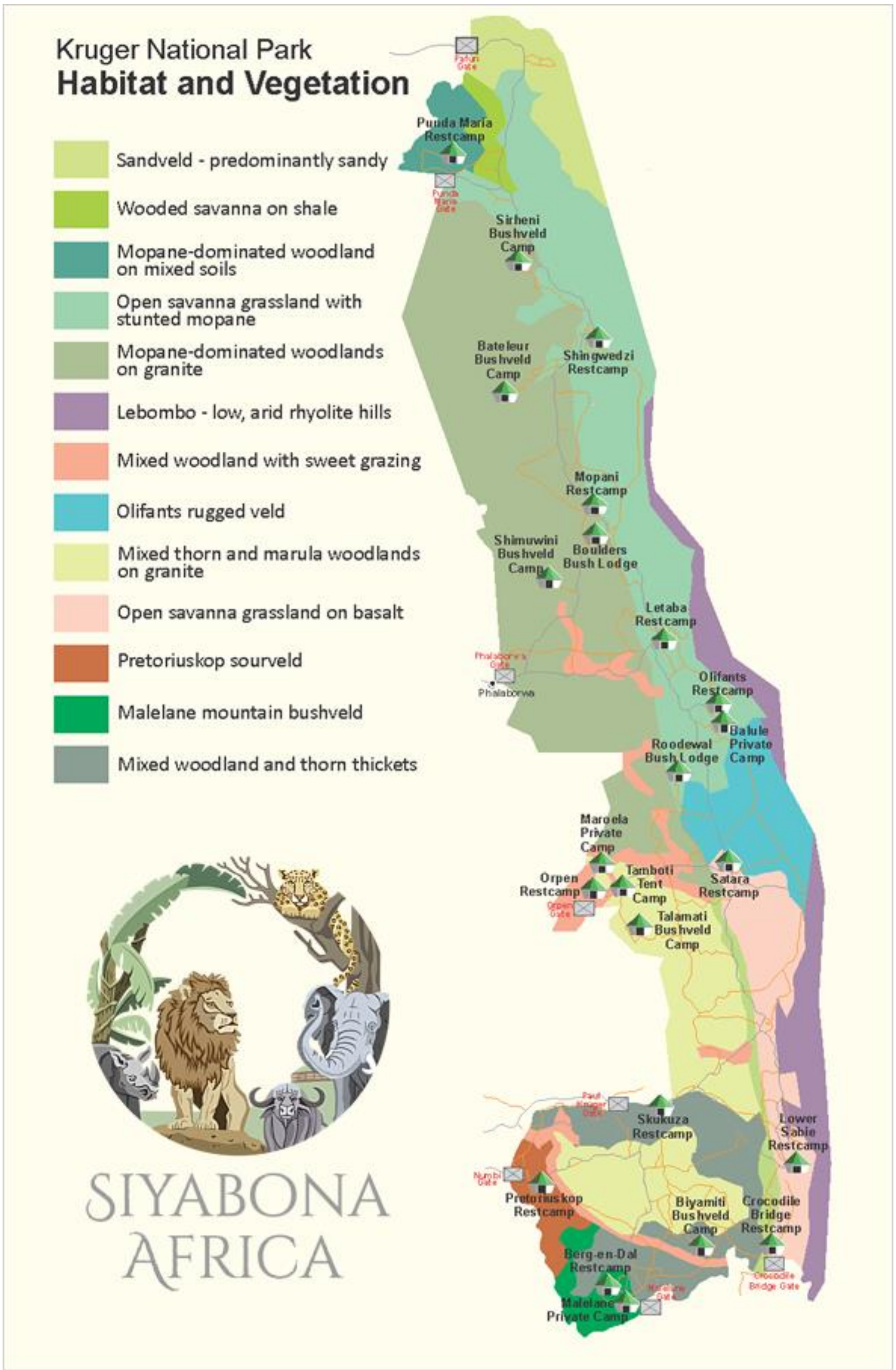

Figure 3.2 Vegetation zones of the Kruger National Park (Siyabona Africa 2016, Mucina and Rutherford 2006, Gertenbach 1983).

Bush Encroachment in the Kruger National Park

Savannas support a large diversity of herbivores (du Toit and Cumming 1999). Many of these herbivores are grazers. Bush encroachment leads to the increase in the woody cover layer at the expense of the grassy layer in savanna habitats, which can reduce the carrying capacity for grazing ungulates, but increase the carrying capacity of browsers. KNP is the largest savanna area under conservation in South Africa (Munyati and Sinthumule 2016). Therefore, it plays a crucial role in savanna biodiversity conservation.

Historically, there used to be a large-scale seasonal east-west migration of herbivores from the area which now comprises KNP towards the Drakensberg mountain range in the Lowveld (Peel et al. 2004). Fire was probably the most important environmental factor which ensured the dominance of the grassy layer in the savanna and woodland areas of the Lowveld (O'Connor et al. 2014). The grassy layer in wooded savanna consists mostly of heliophilous (needs, or tolerates, a high level of direct sunlight) C_4 grasses and sedges and the woody layer consists of mature trees and scattered shrubs (Peel et al. 2004). In the 1960's fences were erected to help with protecting the wildlife in the park, but this also stopped the seasonal migrations. These boundary fences made it necessary for the park to create artificial waterholes in areas that are usually dry outside of the rainy season. Stopping the seasonal migrations and keeping the wildlife in one place led to increased grazing pressure, and along with fire suppression, this has promoted bush thickening and bush encroachment (O'Connor et al. 2014, Peel 2005). Bush thickening not only affects wildlife composition and abundance, but also has an impact on the tourism industry in this area as well.

The KNP and the surrounding nature reserves attract hundreds of thousands of tourists every year. Such visitors are important for the local and national economy and many people's livelihoods depend on tourism and its associated industries for their livelihoods. Tourism is currently the world's fastest growing sector, with annual revenues of almost $500 billion per year (SANParks 2008). The South African tourism industry had an average growth of 6 % for the period 2003–2007 and continues to grow (SANParks 2008). For the second quarter of 2016, international tourist arrivals in South Africa showed positive growth across all regions (South African Tourism 2016). For the second quarter of 2016, for example, international tourist arrivals grew by 11.6% to 2.2 million people (South African Tourism 2016). Bush encroachment adversely impacts the nature- and wildlife-based tourist operations in the Lowveld and elsewhere in southern Africa (Gray 2011), because in areas where the woody layer has become too dense game visibility is reduced. In response to this phenomenon, bush clearing has become a necessary land management practice.

Eckhardt et al. (2000) analysed aerial photographs taken in 1940, 1974 and 1998 as well as fixed-point photographs taken in 1984 and 1996 in the KNP and found that woody cover (trees and shrubs combined) had increased by 12% on granite substrates in the park. Worryingly, the overall density of the large tree component of woody cover had decreased leaving only dense stands of shrubs and/or smaller trees (Eckhardt et al. 2000). In the KNP, many large trees have been lost from certain areas in the park, presumably as a result of elephant impact (Owen-Smith et al. 2006), and in some cases the big trees have been replaced by a denser shrub cover (Owen-Smith et al. 2006).

In a study by Munyati and Sinthumule (2016) historical high spatial resolution panchromatic (a type of black-and-white photographic emulsion that is sensitive to all wavelengths of visible light) aerial photographs were used to determine the extent of woody cover increase in the KNP. It was determined that woody cover has increased in the northern regions of the KNP for the period 1942 to 1977 (Munyati and Sinthumule 2016). In contrast to the north, their results also showed a 29% reduction in woody cover for the southern granites and basalts in the park.

Woody cover abundance and structure depends on several factors at any particular savanna site. It is influenced by the underlying geology, climate, and the disturbance (like fires or grazing) frequency (De Michele et al. 2011). Elephants and fire seem to have substantial effects on woody cover in the KNP (Trollope et al. 1998, Brits et al. 2002, Higgins et al. 2007) although Owen-Smith et al. (2006) found that the effects of elephant herbivory have been exaggerated. It is to be expected that when large herbivores are re-introduced into an environment from which they have been absent for some time they will have an impact on the vegetation. Owen-Smith et al. (2006) writes: “when areas that later became part of the KNP were first given protected status in 1898, no more than 10–20 elephants remained, and reports indicate few elephants in the region earlier in the 19th century. Since there is clearly nothing unsuitable about the habitats in the KNP to support elephants, this seems to be an indication of how effectively the ivory trade had eliminated elephants across large parts of Africa. Hence the vegetation recorded historically in the KNP assumed its form in the absence of elephants, together with low densities of other large herbivores. The state of the vegetation must inevitably be changed following increases in the abundance of elephants and other species.” Could it be that our frame of reference for what the vegetation in the Kruger should look like is mistakenly based on an era when there were little to no elephants in the area?

The impacts of fire on woody vegetation depends on the climate, herbivory in the area, soils as well as the fire intensity and frequency (Enslin et al. 2000). Some trees and shrubs can become denser, increasing the number of regenerative stems after a fire event (Rushworth *pers. comms.*). In a study on the impacts of fire in savanna ecosystems, Higgins et al. (2007) found that fire did not influence tree density, but it did influence the structure, size, and biomass of tree populations. Most savanna tree species are able to regenerate from their root stocks, which makes them quite resilient to fire (Hoffmann and Solbrig 2003; Nefabas and Gambiza 2007). This often means that trees might be kept small by repeated fires, but mortalities are low and large trees are usually immune to life-threatening fire damage (Smit et al. 2010). The timing of fires is important too. Spring fires (late dry season) have been found to reduce woody vegetation the most (Smit et al. 2010). This is something to keep in mind in land management plans.

Methods

For this analysis, I used the SABAP2 data for the area in South Africa north of 26°S and E of 31°E, an area slightly larger than the KNP which includes the rural areas and private nature reserves on the western border of the KNP. In this area, every pentad has at least four full protocol SABAP2 checklists, as a consequence of the so called “Turning Kruger Green” initiative by a group of bird atlasers in the region (Roerig 2016). Given that the minimum duration of fieldwork for each checklist is two hours, this means that each pentad has at least eight hours of intensive fieldwork. The study area included 417 pentads. Bird species occurring in 30 or more pentads within the study area were included in the analysis.

I used exploratory data analysis methods developed in Chapter 2 to relate woody cover density to bird distributions. In brief, the method uses two databases: (1) the SABAP2 database on pentad scale for bird distributions (2) the CSIR LiDAR data to give c. 400 measurements of woody cover per pentad. As in Chapter 2, the output of this method is an array of length 20 for each bird species, quantifying its preference/avoidance, on a scale running from –1 to +1, of each woody cover class, from 0–5%, 5–10%, …, 95–100%. The array of length 20 can be thought of as the preference “signature” for a bird species in relation to woody cover.

As in Chapter 2, I formed groups of species with similar “signatures” and a non-hierarchical classification was performed, as described by Friedman and Rubin (1967). Non-hierarchical classification divides the species into a predetermined number of groups, on the basis of their signatures, so that each group contains species with similar signatures. Various criteria exist to measure the performance of a particular grouping. The criterion I used maximizes the total Euclidean distance between the groups, which is the same as minimizing the sums of squares within groups. This criterion is a looser alternative to one that assumes that the data consists of a mixture of multivariate normal distributions with a common covariance matrix. These two assumptions would not be true of the signatures for the bird species. The analysis was performed using the Cluster directive of Genstat Seventeenth Edition (2014). The number of groups selected was based on a judgement of when the criterion was no longer decreasing substantially as further groups were added (the "elbow" method) (Tibshirani et al. 2001). Since the objective is to undertake an exploratory data analysis, the subjective choice in this way is satisfactory. I computed the "average signature" for the species assigned to each group. I undertook a visual comparison of the signatures of the species assigned to a group and the average signature for the group. The average signatures for the groups were assembled into a rectangular data matrix with a row for each of the groups, and with 20 columns, one for each woody cover category. From this matrix, a dissimilarity matrix was constructed, using Euclidean distances between the rows of the rectangular matrix. The dissimilarity matrix was a symmetric matrix, with elements representing the Euclidean distances between the average signatures for each group of species.

I used non-metric multidimensional scaling (Kruskal 1964; Greenacre and Underhill 1982) as implemented in GenStat Seventeenth Edition (2014) to transform the dissimilarity matrix into a configuration of points in two dimensions in which the ordering of the distances between the points representing the ordering of the distances between the groups in the dissimilarity matrix. Each point in this configuration represents one of the groups determined by the non-hierarchical cluster analysis. Groups with similar signatures are plotted close together. Careful inspection of the plot provides insights into the groups of particular interest, those groups with peaked signatures suggest they contain the species most sensitive to woody cover.

Results

A total of 10,806 SABAP2 checklists were available for the KNP study area, containing a total of 643,629 records of bird species distribution. The mean number of species per checklist was therefore 59.6. 370 species were recorded in 30 or more pentads in the KNP study area. The matrix with 370 rows (one for each species) and 20 columns (one for each woody cover class), in which each row was the signature for a species was subjected to the non-hierarchical cluster analysis. The "elbow method" suggested 25 groups (by coincidence the same number as in Chapter 2). If more than 25 groups had been selected, the sums of squares criterion would have started to decrease more slowly than in the requesting smaller numbers of groups, suggesting that 25 groups was a good stopping point.

The allocation of the 370 species to the 25 groups is provided in the first data column of Table 3.1. The largest of the 25 groups had 41 members (Group 12). Group 2 had only one member, Osprey *Pandion haliaetus*. Two groups had two members: Groups 20 and 25 (Table 3.1). The two most important statistics provided in Table 1 are the maximum value of Jacobs' Index in the signature for each species (third column of data), and also the woody cover class in which the maximum occurred (column headed Maximum, which gives the lower value of the height class interval; e.g. 70 means 70–75%). The species with the largest preference for a single woody cover class was Olive Sunbird *Cyanomitra olivacea*, the Jacobs' Index preference of 0.796 for the 95–100% woody cover class (Table 3.1). This value provides a gold standard against which to measure the Jacobs' Index for species in this study. Olive Sunbird is in Group 19 (shaded brown in Table 3.1) and the remaining species in this group had similar maximum values for Jacob's Index (Table 3.1).

The remaining columns of Table 3.1 provide a set of summary data for the species. The second column of data provides the number of pentads in which the species was recorded. So, for example, the first species in the table, Southern Grey-headed Sparrow *Passer diffusus* occurs in 404 pentads in the KNP, and had maximum Jacobs' Index of 0.056 (which is relatively low, compared with the gold standard). The final four columns in Table 3.1 are most easily explained through examples. The column labelled "Maximum" contains the woody cover class which had the maximum Jacobs' Index preference. The column headed "Lower" to its left is the woody cover class where the Jacobs' Index line for the species (the signature) dipped below 0 to the left of the maximum for the first time, and the column labelled "Upper" is where it dipped below 0 to the right of the maximum. The column headed "Crossings" give the number of times the signature line crossed the zero line. For the Grey-headed Sparrow the maximum value for the Jacobs' Index was for woody cover class 50–55%, and the signature was above zero from the 15–20% class to the 70–75% woody cover class. The signature line crossed zero line twice.

Species which cross the zero line once occur either when a species has a strong preference for open habitats and the signature line drops below the zero line when the woody cover percentage gets too high, or when the species prefers dense woody cover and the signature line drops below the zero line when the woody cover is not dense enough. Species in Group 13 (shaded yellow in Table

3.1) and Group 19 (shaded brown in Table 3.1) have a single crossing. Species with two crossings have a preferred range of woody cover, avoiding places where the woody cover is either not thick enough or too thick. All except one species in Group 5 (shaded green in Table 3.1) have two crossings, indicating a preference for an intermediate range of woody cover.

Table 3.1 These 370 species occur in 30 or more pentads in the Kruger National Park study area. The species are ordered first by the groups to which they were allocated by the non-hierarchical clustering, and then by the number of pentads in the study area in which they were recorded. The maximum value of the Jacobs' Index for any woody cover class is given; it is always positive. The woody cover class with this maximum value is provided as well as the woody cover classes below and above it at which the Jacobs' Index changes from being positive to negative; these three columns are headed Lower, Maximum and Upper. The lower boundary of the woody cover class is given (so 50 means the 50–55% woody cover class). The column headed Crossings gives the number of times the Jacobs' Index line (the signature of the species) crossed the zero line. See text for further detail and explanation. Three groups are colour coded (see text for explanation). The final column, Conservation Status, gives the conservation status in South Africa, Lesotho and Swaziland for species that are listed as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Near Threatened (NT), as listed on the official BirdLife South Africa (2017) species checklist.

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Southern Grey-headed Sparrow	1	404	0.056	15	50	70	2	
Laughing Dove	1	402	0.054	30	75	75	6	
Red-faced Mousebird	1	369	0.103	30	70	80	4	
Helmeted Guineafowl	1	329	0.076	30	75	75	3	
Willow Warbler	1	322	0.088	30	60	95	1	
African Green-Pigeon	1	292	0.089	20	70	90	2	
Red-billed Firefinch	1	257	0.141	25	70	90	2	
Lesser Masked-Weaver	1	233	0.106	35	65	80	6	
Black Crake	1	225	0.146	35	75	95	1	
White-faced Duck	1	204	0.161	45	75	95	3	
African Jacana	1	186	0.127	30	75	80	4	
Common House-Martin	1	168	0.068	35	65	90	3	
Little Grebe	1	133	0.102	30	60	95	1	
Black-crowned Night-Heron	1	57	0.125	30	70	90	2	
Osprey	2	44	0.371	5	5	5	5	
Zitting Cisticola	3	219	0.501	0	0	10	1	
Common Ostrich	3	126	0.604	0	0	10	1	
Kurrichane Buttonquail	3	123	0.261	0	0	10	1	
White Stork	3	102	0.370	0	0	10	1	
Shelley's Francolin	3	59	0.163	0	0	25	1	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Plain-backed Pipit	3	45	0.288	0	0	15	2	
Common Quail	3	34	0.463	0	0	5	1	
Rattling Cisticola	4	398	0.076	0	0	35	1	
Lilac-breasted Roller	4	347	0.106	0	0	35	1	
Red-backed Shrike	4	347	0.130	0	0	35	1	
African Grey Hornbill	4	339	0.088	5	25	40	2	
Bateleur	4	334	0.071	0	15	40	1	EN
Crowned Lapwing	4	305	0.100	0	0	30	1	
European Roller	4	294	0.126	0	0	35	1	NT
Red-billed Buffalo-Weaver	4	283	0.162	0	0	35	1	
Greater Blue-eared Starling	4	274	0.062	10	15	45	2	
Pearl-spotted Owlet	4	267	0.087	15	30	45	3	
Tawny Eagle	4	259	0.067	10	25	45	2	EN
Wattled Starling	4	250	0.267	0	0	20	1	
Purple Roller	4	241	0.204	0	0	25	1	
Red-breasted Swallow	4	237	0.116	0	0	40	1	
Long-tailed Paradise-Whydah	4	237	0.142	0	0	30	1	
Burchell's Starling	4	205	0.096	0	0	45	1	
Southern Carmine Bee-eater	4	202	0.248	0	0	25	1	
Lappet-faced Vulture	4	195	0.185	0	0	10	5	EN
Gabar Goshawk	4	190	0.090	5	20	40	2	
White-headed Vulture	4	185	0.141	0	0	35	1	CR
Lesser Spotted Eagle	4	138	0.115	0	0	40	1	
Senegal Lapwing	4	96	0.047	0	5	45	1	
Steppe Eagle	4	92	0.139	0	0	35	1	
Common Swift	4	83	0.213	0	0	5	5	
Icterine Warbler	4	76	0.074	0	0	10	5	
Common Cuckoo	4	56	0.149	0	0	5	3	
Southern Yellow-billed Hornbill	5	367	0.102	10	25	45	2	
Double-banded Sandgrouse	5	234	0.167	10	25	45	2	
Southern Ground-Hornbill	5	217	0.097	10	25	45	2	EN
Dark Chanting Goshawk	5	177	0.163	10	25	45	2	
Yellow-bellied Eremomela	5	157	0.149	10	25	45	2	
Bennett's Woodpecker	5	146	0.133	10	15	40	2	
Eurasian Golden Oriole	5	143	0.119	15	35	50	2	
African Scops-Owl	5	139	0.120	15	40	50	2	
Dusky Lark	5	105	0.167	10	25	45	2	
Bushveld Pipit	5	92	0.101	10	15	45	2	
Coqui Francolin	5	87	0.166	10	25	45	2	
Southern White-faced Scops-Owl	5	77	0.162	15	30	50	2	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Violet-eared Waxbill	5	61	0.156	15	40	55	2	
Shaft-tailed Whydah	5	42	0.257	5	20	30	2	
Marico Flycatcher	5	41	0.094	0	0	15	3	
Sabota Lark	6	307	0.208	0	0	30	1	
Red-crested Korhaan	6	305	0.138	0	0	35	1	
Swainson's Spurfowl	6	303	0.255	0	0	25	1	
Magpie Shrike	6	303	0.302	0	0	20	1	
Namaqua Dove	6	225	0.344	0	0	20	1	
Amur Falcon	6	197	0.277	0	0	25	1	
Lesser Grey Shrike	6	171	0.463	0	0	15	1	
Flappet Lark	6	147	0.413	0	0	15	1	
Black-bellied Bustard	6	131	0.400	0	0	15	1	
Monotonous Lark	6	114	0.157	0	0	30	1	
Harlequin Quail	6	92	0.247	0	0	25	1	
Temminck's Courser	6	80	0.384	0	0	10	1	
Lark-like Bunting	6	79	0.365	0	0	15	3	
Buffy Pipit	6	72	0.293	0	0	30	1	
African Quailfinch	6	66	0.511	0	0	10	1	
Kittlitz's Plover	6	56	0.314	0	0	20	1	
Red-headed Finch	6	37	0.488	0	0	15	1	
Arrow-marked Babbler	7	378	0.059	10	25	45	2	
Crested Francolin	7	351	0.083	15	40	55	2	
Grey Go-away-bird	7	346	0.105	15	35	55	2	
Red-billed Oxpecker	7	334	0.088	10	25	50	2	
Red-billed Hornbill	7	322	0.092	15	35	55	2	
Wahlberg's Eagle	7	312	0.082	10	25	50	2	
Brown-headed Parrot	7	260	0.077	10	40	50	2	
African Hawk-Eagle	7	233	0.130	15	35	60	2	
Martial Eagle	7	233	0.089	10	35	50	2	
Levaillant's Cuckoo	7	226	0.089	15	35	50	2	
Stierling's Wren-Warbler	7	222	0.135	15	40	60	2	
Hooded Vulture	7	200	0.101	25	40	60	2	CR
Saddle-billed Stork	7	182	0.106	10	35	50	2	EN
Southern White-crowned Shrike	7	168	0.153	20	35	65	2	
Verreaux's Eagle-Owl	7	161	0.125	15	40	50	2	
Shikra	7	140	0.118	15	35	60	2	
Cape Vulture	7	132	0.052	25	40	60	3	EN
Purple Indigobird	7	123	0.136	20	45	50	4	
Bronze-winged Courser	7	115	0.119	15	35	50	2	
African Spoonbill	7	112	0.135	15	35	55	2	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
African Barred Owlet	7	85	0.182	20	40	60	2	
European Nightjar	7	55	0.128	15	40	50	2	
Collared Pratincole	7	31	0.123	10	35	50	2	
Spotted Thick-knee	8	136	0.253	80	85	85	10	
Square-tailed Nightjar	8	124	0.207	80	85	85	4	
Great Spotted Cuckoo	8	109	0.374	80	85	85	5	
Emerald-spotted Wood-Dove	9	409	0.106	25	50	85	2	
Grey-headed Bush-Shrike	9	351	0.140	25	70	95	1	
Orange-breasted Bush-Shrike	9	350	0.146	35	70	95	1	
Cardinal Woodpecker	9	337	0.111	25	75	95	1	
Wire-tailed Swallow	9	263	0.153	30	75	95	1	
African Pied Wagtail	9	226	0.138	25	60	95	1	
Grey Penduline-Tit	9	194	0.129	25	65	90	2	
Fiery-necked Nightjar	9	163	0.119	20	40	80	4	
Lizard Buzzard	9	144	0.113	20	70	95	1	
Green-capped Eremomela	9	62	0.261	35	70	80	6	
Glossy Ibis	9	42	0.210	25	80	95	1	
Fork-tailed Drongo	10	410	0.060	15	30	60	2	
White-browed Scrub-Robin	10	409	0.069	20	55	75	2	
Natal Spurfowl	10	374	0.087	15	30	55	2	
Common Scimitarbill	10	328	0.101	15	40	65	2	
African Hoopoe	10	325	0.077	15	35	70	2	
Egyptian Goose	10	314	0.086	15	35	60	4	
Little Bee-eater	10	314	0.096	25	50	80	6	
White-crested Helmet-Shrike	10	312	0.108	15	40	60	2	
Cinnamon-breasted Bunting	10	311	0.078	10	25	40	8	
Hamerkop Hamerkop	10	301	0.084	20	45	70	2	
African Fish-Eagle	10	290	0.093	20	35	70	2	
Bearded Woodpecker	10	280	0.106	25	35	75	2	
Groundscraper Thrush	10	258	0.076	15	25	60	2	
Pied Kingfisher	10	250	0.112	20	45	75	2	
Jameson's Firefinch	10	250	0.078	15	35	70	2	
Red-headed Weaver	10	246	0.074	15	35	70	2	
Green-backed Heron	10	216	0.113	20	45	75	2	
Wood Sandpiper	10	205	0.067	25	60	70	4	
Striped Kingfisher	10	193	0.085	25	50	70	4	
Acacia Pied Barbet	10	191	0.139	15	35	70	2	
Greater Honeyguide	10	186	0.098	15	20	45	8	
Common Greenshank	10	169	0.120	25	60	70	4	
Common Sandpiper	10	165	0.099	25	35	75	2	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Great Egret	10	138	0.123	15	45	75	2	
Goliath Heron	10	126	0.151	20	45	75	2	
Little Egret	10	125	0.139	25	45	75	2	
Alpine Swift	10	121	0.129	20	45	75	2	
Mosque Swallow	10	112	0.125	25	50	75	6	
Barn Owl	10	90	0.126	30	70	75	2	
Squacco Heron	10	70	0.129	25	45	75	2	
Grey-headed Kingfisher	10	66	0.122	25	40	75	2	
Yellow-billed Egret	10	60	0.101	15	35	75	2	
Black-backed Puffback	11	401	0.247	35	90	95	1	
Black-headed Oriole	11	390	0.239	30	90	95	1	
White-bellied Sunbird	11	384	0.251	35	75	95	1	
Brown-hooded Kingfisher	11	369	0.270	35	95	95	1	
African Paradise-Flycatcher	11	339	0.375	35	95	95	1	
Golden-tailed Woodpecker	11	319	0.307	30	95	95	1	
Kurrichane Thrush	11	310	0.316	35	95	95	1	
Black-collared Barbet	11	305	0.325	35	90	95	1	
Southern Black Flycatcher	11	303	0.264	30	95	95	1	
Hadeda Ibis	11	283	0.362	35	90	95	1	
African Palm-Swift	11	269	0.333	35	95	95	1	
White-fronted Bee-eater	11	211	0.341	35	85	95	1	
Reed Cormorant	11	190	0.300	35	75	95	1	
Dusky Indigobird	11	156	0.406	40	95	95	1	
Grey-rumped Swallow	11	149	0.286	30	85	95	1	
White-breasted Cormorant	11	141	0.301	35	95	95	1	
Little Sparrowhawk	11	141	0.277	35	90	95	3	
African Black Swift	11	131	0.364	30	90	95	1	
Bearded Scrub-Robin	11	105	0.329	35	70	95	1	
Purple Heron	11	91	0.282	30	95	95	1	
African Cuckoo Hawk	11	39	0.343	35	75	95	1	
Speckled Pigeon	11	36	0.377	35	70	95	1	
Little Bittern	11	35	0.274	35	95	95	1	
Cape Turtle-Dove	12	405	0.048	10	35	45	3	
Long-billed Crombec	12	404	0.068	10	30	50	2	
Blue Waxbill	12	401	0.049	10	25	50	2	
Cape Glossy Starling	12	398	0.030	20	30	55	4	
Chinspot Batis	12	392	0.088	15	40	60	2	
Southern Black Tit	12	383	0.111	15	30	55	2	
Brown-crowned Tchagra	12	374	0.064	15	35	60	2	
Golden-breasted Bunting	12	373	0.089	10	25	50	2	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Brubru	12	361	0.088	15	35	50	2	
Green Wood-Hoopoe	12	355	0.101	15	35	55	2	
Crested Barbet	12	353	0.081	10	25	50	2	
Spotted Flycatcher	12	335	0.046	15	30	60	2	
White-backed Vulture	12	326	0.053	10	35	50	2	CR
Woodland Kingfisher	12	324	0.061	10	25	45	2	
Brown Snake-Eagle	12	309	0.068	10	20	40	2	
Three-banded Plover	12	294	0.068	15	35	50	4	
Marico Sunbird	12	288	0.067	20	35	60	4	
Blacksmith Lapwing	12	287	0.113	15	35	55	2	
Green-winged Pytilia	12	283	0.035	0	0	5	9	
Yellow-throated Petronia	12	282	0.099	10	15	45	2	
Jacobin Cuckoo	12	261	0.067	25	35	60	2	
Yellow-billed Kite	12	245	0.055	25	35	60	2	
Grey Heron	12	241	0.090	15	35	55	2	
Water Thick-knee	12	233	0.102	15	35	60	2	
Black-chested Snake-Eagle	12	183	0.044	15	25	50	2	
African Cuckoo	12	183	0.086	10	25	50	2	
Pale Flycatcher	12	175	0.092	15	55	65	2	
Woolly-necked Stork	12	166	0.053	25	35	50	4	
Comb Duck	12	159	0.073	15	35	50	2	
Marabou Stork	12	155	0.096	25	35	50	6	NT
Yellow-billed Oxpecker	12	154	0.079	15	35	40	4	
Black Stork	12	146	0.068	10	35	50	2	VU
Yellow-billed Stork	12	118	0.092	15	35	50	4	EN
Black-winged Stilt	12	109	0.118	15	45	60	4	
African Openbill	12	106	0.089	10	35	50	4	
Greater Painted-snipe	12	64	0.130	15	35	50	2	
Ruff	12	59	0.130	5	5	5	4	
Marsh Sandpiper	12	58	0.081	10	35	55	2	
Olive-tree Warbler	12	57	0.106	35	65	65	8	
Little Stint	12	50	0.107	15	35	55	2	
Booted Eagle	12	34	0.085	25	25	60	2	
Chestnut-backed Sparrowlark	13	112	0.712	0	0	10	1	
Kori Bustard	13	102	0.598	0	0	10	1	NT
Secretarybird	13	70	0.572	0	0	10	1	VU
Desert Cisticola	13	62	0.705	0	0	10	1	
Red-capped Lark	13	32	0.689	0	0	10	1	
Grey Tit-Flycatcher	14	198	0.165	30	65	95	1	
Retz's Helmet-Shrike	14	166	0.175	30	60	95	1	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Brown-throated Martin	14	133	0.168	25	60	95	1	
African Darter	14	131	0.174	30	75	95	1	
Horus Swift	14	84	0.202	25	70	95	1	
White-crowned Lapwing	14	58	0.292	30	60	80	4	
African Sacred Ibis	14	39	0.276	25	75	90	2	
Yellow-bellied Greenbul	15	98	0.392	35	70	95	1	
Broad-billed Roller	15	55	0.434	35	80	95	1	
Crested Guineafowl	15	39	0.458	35	60	80	2	
Tropical Boubou	15	35	0.418	35	90	95	1	
Southern Boubou	16	277	0.583	45	95	95	1	
Sombre Greenbul	16	261	0.538	45	95	95	1	
African Firefinch	16	212	0.627	45	95	95	1	
Bronze Mannikin	16	187	0.548	45	95	95	1	
Purple-crested Turaco	16	181	0.625	45	95	95	1	
Terrestrial Brownbul	16	164	0.571	40	95	95	1	
Collared Sunbird	16	164	0.548	40	90	95	1	
Yellow-fronted Tinkerbird	16	160	0.594	40	95	95	1	
Thick-billed Weaver	16	136	0.620	45	95	95	1	
African Goshawk	16	128	0.540	40	90	95	1	
Gorgeous Bush-Shrike	16	126	0.621	40	95	95	1	
Red-collared Widowbird	16	118	0.616	45	95	95	1	
Cape Wagtail	16	108	0.644	45	90	95	1	
Trumpeter Hornbill	16	106	0.541	40	85	95	1	
Eastern Nicator	16	98	0.613	40	95	95	1	
Greater Striped Swallow	16	85	0.683	50	90	95	1	
Crowned Hornbill	16	77	0.509	35	90	95	1	
Brown-backed Honeybird	16	67	0.575	45	95	95	1	
Brimstone Canary	16	59	0.616	45	95	95	1	
Rock Martin	16	50	0.588	35	90	95	1	
Long-crested Eagle	16	45	0.636	45	95	95	1	
Black Sparrowhawk	16	45	0.631	45	95	95	1	
Dark-capped Yellow Warbler	16	34	0.615	45	95	95	1	
Cape Weaver	16	32	0.666	45	95	95	1	
African Wood-Owl	16	31	0.594	40	95	95	1	
Lesser Striped Swallow	17	347	0.255	35	95	95	1	
Neddicky Neddicky	17	326	0.225	50	95	95	3	
Violet-backed Starling	17	321	0.170	25	95	95	1	
Klaas's Cuckoo	17	268	0.224	35	90	95	1	
Black Cuckooshrike	17	256	0.181	25	85	95	1	
White-rumped Swift	17	254	0.226	35	95	95	1	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
House Sparrow	17	200	0.199	40	75	95	1	
Giant Kingfisher	17	197	0.234	30	90	95	1	
African Harrier-Hawk	17	187	0.214	35	90	95	1	
Malachite Kingfisher	17	186	0.208	30	85	95	1	
Spur-winged Goose	17	123	0.193	35	90	95	1	
Mocking Cliff-Chat	17	99	0.255	45	85	95	3	
Spotted Eagle-Owl	17	97	0.227	25	90	95	1	
Pearl-breasted Swallow	17	59	0.198	35	90	95	3	
Great Reed-Warbler	17	52	0.198	45	85	95	3	
Dwarf Bittern	17	50	0.307	45	85	90	6	
Rock Dove	17	49	0.224	35	90	95	1	
Burchell's Coucal	18	348	0.080	35	90	95	1	
Diderick Cuckoo	18	333	0.103	35	85	95	1	
White-winged Widowbird	18	275	0.154	0	0	5	2	
Black-shouldered Kite	18	234	0.252	0	0	10	4	
Eurasian Hobby	18	79	0.128	50	90	95	3	
Amethyst Sunbird	19	160	0.703	45	95	95	1	
Cape White-eye	19	158	0.718	45	95	95	1	
Streaky-headed Seedeater	19	126	0.653	45	95	95	1	
Red-capped Robin-Chat	19	122	0.643	40	85	95	1	
Bar-throated Apalis	19	119	0.715	50	95	95	1	
Tambourine Dove	19	116	0.706	45	95	95	1	
Lazy Cisticola	19	86	0.714	45	95	95	1	
Yellow-rumped Tinkerbird	19	81	0.728	45	95	95	1	
Golden Weaver	19	74	0.692	45	95	95	1	
Black Saw-wing	19	70	0.708	45	95	95	1	
Scaly-throated Honeyguide	19	57	0.747	50	85	95	1	
Olive Bush-Shrike	19	51	0.741	50	95	95	1	
Cape Batis	19	50	0.771	50	95	95	1	
Striped Pipit	19	50	0.722	45	95	95	1	
Cape Robin-Chat	19	48	0.717	50	95	95	1	
Black-bellied Starling	19	48	0.715	45	95	95	1	
African Crowned Eagle	19	45	0.688	45	95	95	1	VU
Red-backed Mannikin	19	44	0.697	45	95	95	1	
Square-tailed Drongo	19	43	0.770	45	95	95	1	
Narina Trogon	19	41	0.772	50	95	95	1	
Greater Double-collared Sunbird	19	41	0.738	45	95	95	1	
Half-collared Kingfisher	19	36	0.715	45	95	95	1	
Olive Woodpecker	19	36	0.757	45	90	95	1	
Cape Canary	19	36	0.748	50	90	95	1	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
Southern Double-collared Sunbird	19	34	0.770	50	90	95	1	
Swee Waxbill	19	34	0.775	55	90	95	1	
Olive Sunbird	19	31	0.796	45	95	95	1	
Village Indigobird	20	156	0.237	35	85	90	2	
Cut-throat Finch	20	112	0.265	55	70	90	4	
Tawny-flanked Prinia	21	409	0.329	40	95	95	1	
Yellow-fronted Canary	21	399	0.378	40	95	95	1	
White-throated Robin-Chat	21	271	0.352	40	85	95	1	
Red-faced Cisticola	21	264	0.324	40	95	95	1	
Pin-tailed Whydah	21	253	0.358	45	95	95	1	
Cattle Egret	21	240	0.209	45	75	95	1	
Steppe Buzzard	21	214	0.366	45	95	95	1	
Yellow-throated Longclaw	21	200	0.402	45	95	95	1	
Southern Red Bishop	21	181	0.261	45	95	95	1	
Marsh Warbler	21	156	0.392	45	95	95	1	
Pied Crow	21	150	0.247	45	90	95	1	
African Wattled Lapwing	21	132	0.223	40	75	95	1	
Black-headed Heron	21	123	0.422	45	85	95	1	
Lesser Swamp-Warbler	21	88	0.290	45	80	95	1	
Common Moorhen	21	63	0.408	45	90	95	2	
Orange-breasted Waxbill	21	44	0.387	45	95	95	1	
Rufous-winged Cisticola	21	35	0.434	40	80	95	1	
Dark-capped Bulbul	22	379	0.429	40	90	95	1	
Yellow-breasted Apalis	22	341	0.390	35	95	95	1	
Green-backed Camaroptera	22	335	0.521	40	95	95	1	
Red-eyed Dove	22	323	0.471	40	95	95	1	
Spectacled Weaver	22	296	0.444	40	85	95	1	
Common Waxbill	22	271	0.429	40	95	95	1	
Speckled Mousebird	22	266	0.423	45	95	95	1	
Red-chested Cuckoo	22	239	0.400	40	85	95	1	
Village Weaver	22	226	0.424	45	95	95	1	
Scarlet-chested Sunbird	22	218	0.418	45	95	95	1	
White-browed Robin-Chat	22	216	0.440	40	95	95	1	
Black Cuckoo	22	176	0.470	40	95	95	1	
Ashy Flycatcher	22	169	0.425	35	90	95	1	
Lesser Honeyguide	22	167	0.444	40	95	95	1	
African Dusky Flycatcher	22	128	0.555	45	90	95	1	
Red-winged Starling	22	128	0.446	35	95	95	1	
Common Fiscal	22	121	0.519	45	95	95	1	
Fan-tailed Widowbird	22	94	0.464	45	95	95	1	

Species	Group	Pentads	Maximum Jacobs' Index	Lower	Maximum	Upper	Crossings	Conservation Status
African Black Duck	22	93	0.558	40	95	95	1	
African Pygmy-Kingfisher	22	92	0.441	35	90	95	1	
Little Rush-Warbler	22	83	0.500	45	95	95	1	
Familiar Chat	22	71	0.505	45	90	95	3	
Common Myna	22	70	0.506	45	90	95	1	
African Reed-Warbler	22	69	0.444	45	85	95	1	
White-throated Swallow	22	66	0.439	45	95	95	1	
Peregrine Falcon	22	55	0.453	45	85	95	1	
Freckled Nightjar	22	54	0.509	35	95	95	1	
Levaillant's Cisticola	22	50	0.524	45	95	95	1	
Purple-banded Sunbird	22	41	0.430	40	80	95	1	
African Stonechat	23	163	0.577	55	90	95	1	
Croaking Cisticola	23	140	0.433	55	95	95	2	
Rock Kestrel	23	41	0.478	55	95	95	2	
Black-crowned Tchagra	24	407	0.048	0	10	30	1	
Barn Swallow	24	406	0.089	0	0	30	1	
European Bee-eater	24	384	0.030	15	35	40	5	
Southern Masked-Weaver	24	348	0.041	40	65	75	3	
Red-billed Quelea	24	334	0.157	0	0	15	1	
African Pipit	24	300	0.204	0	0	5	3	
Little Swift	24	295	0.032	25	35	45	5	
Rufous-naped Lark	24	259	0.157	0	0	20	1	
Burnt-necked Eremomela	24	116	0.076	50	70	70	5	
Lanner Falcon	24	79	0.269	0	0	5	3	VU
African Mourning Dove	24	76	0.184	0	0	10	5	
Fiscal Flycatcher	24	56	0.074	0	0	10	3	
Red-billed Teal	24	55	0.255	0	0	0	3	
Cape Sparrow	24	40	0.176	0	0	5	3	
Grey-backed Camaroptera	25	99	0.398	50	85	90	5	
White-fronted Plover	25	42	0.445	30	90	90	2	

As in Chapter 2, the 25 group signatures were transformed into a 25×25 dissimilarity matrix using Euclidean distances. This matrix was submitted to non-metric multidimensional scaling, and produced the configuration with stress 0.11 (Figure 3.3). Group 13 on the left of Figure 3.3 consists of species preferring open grassland habitat (see the details for the species in this group, and shaded yellow in Table 3.1). Group 19 on the right of Figure 3.3 consists of species preferring dense woody cover (see the details for the species in this group, and shaded brown in Table 3.1).

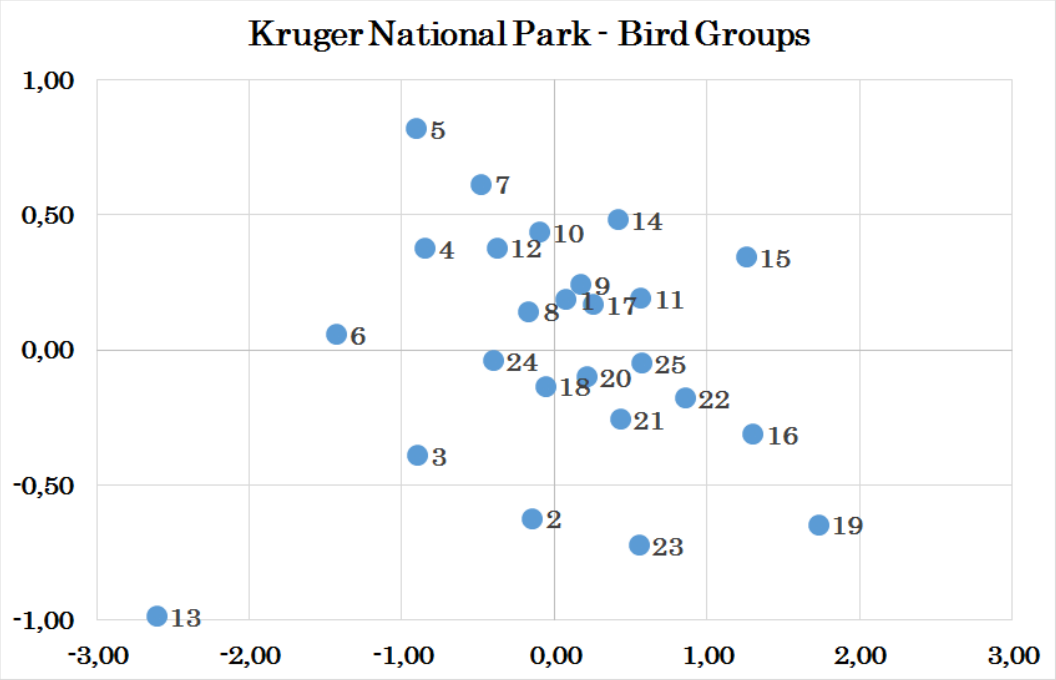

Figure 3.3 The 25 groups generated by the non-hierarchical clustering plotted using non-metric multidimensional scaling.

As in Chapter 2, the "interesting" groups were along the "arch" of Figure 3.3. The bird groups on the outer edge of the plot (Figure 3.3), starting from group 13 to 19, followed a natural progression of birds that prefer open habitats (Group 13) to those that prefer forest habitats (Group 19) (see below). I chose, by visual inspection, the following seven groups to form the "arch": Groups 13, 6, 5, 15, 22, 16 and 19 (Figure 3.3). The most important basis of selection of these groups was a narrow peak of preference for woody cover classes. The relationship between woody cover and species preferences in these seven groups are outlined below. From each group four candidate species for monitoring purposes were chosen. The criteria for selecting the four species were as follows: The selected species within each group are the four species which best represent the woody cover classes that they fall into according to the analysis. And, all four species for each group have a good number of pentads that they occur in within the KNP. The distributions of the selected species within the study area (and the immediate neighbourhood of the study area) are shown using the standard SABAP2 distribution maps on a pentad scale (Underhill and Brooks 2016). Relevant background information to the species within each of these key groups is provided in Appendix 3.A. The remaining groups are considered as "interior" groups and (as in Chapter 2) the species assigned to them are either only weakly sensitive to woody cover, or do not use woody cover as a criterion for their distribution (e.g. waterbirds).

Group 13 consists of species which show a clear preference for open habitats, with woody cover of less than 20% (Figure 3.4). This group includes five species (Table 3.1): Secretarybird *Sagittarius serpentarius* (recorded in 70 pentads), Kori Bustard *Ardeotis kori* (102), Chestnut-backed Sparrowlark *Eremopterix leucotis* (112), Red-capped Lark *Calandrella cinerea* (32) and Desert Cisticola *Cisticola aridulus* (62). These birds are all considered to be birds of open areas with sparse tree cover (Hockey et al. 2005). They have similar SABAP2 distributions within the study area (Figure 3.5). All these species tend to be concentrated towards the eastern areas of the KNP. The Chestnut-backed Sparrowlark, although it occurs in the most pentads, is an irruptive species (Dean 1997a), and therefore not appropriate to select as a species for monitoring purposes, so the remaining four species in the group have been selected.

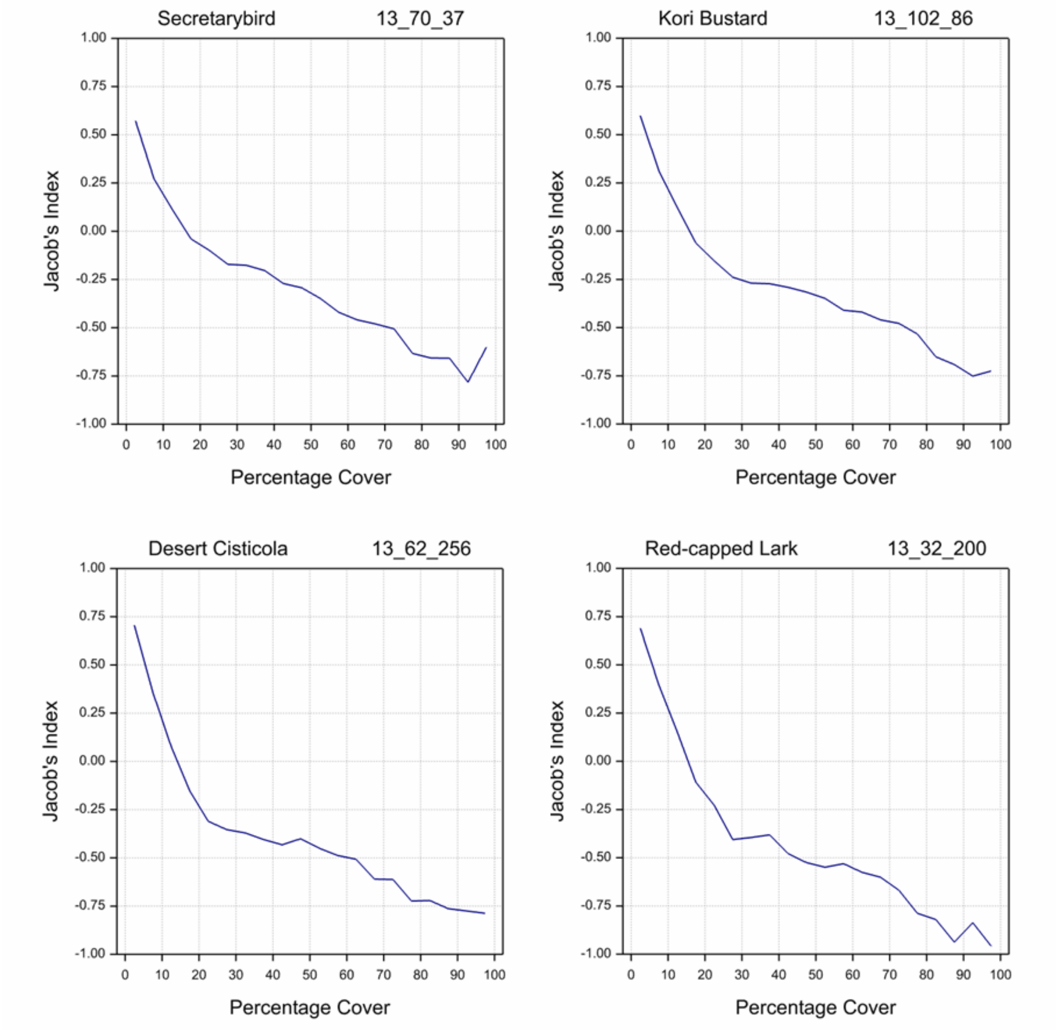

Figure 3.4 Percentage woody cover preference plots for Secretarybird, Kori Bustard, Desert Cisticola and Red-capped Lark (Group 13).

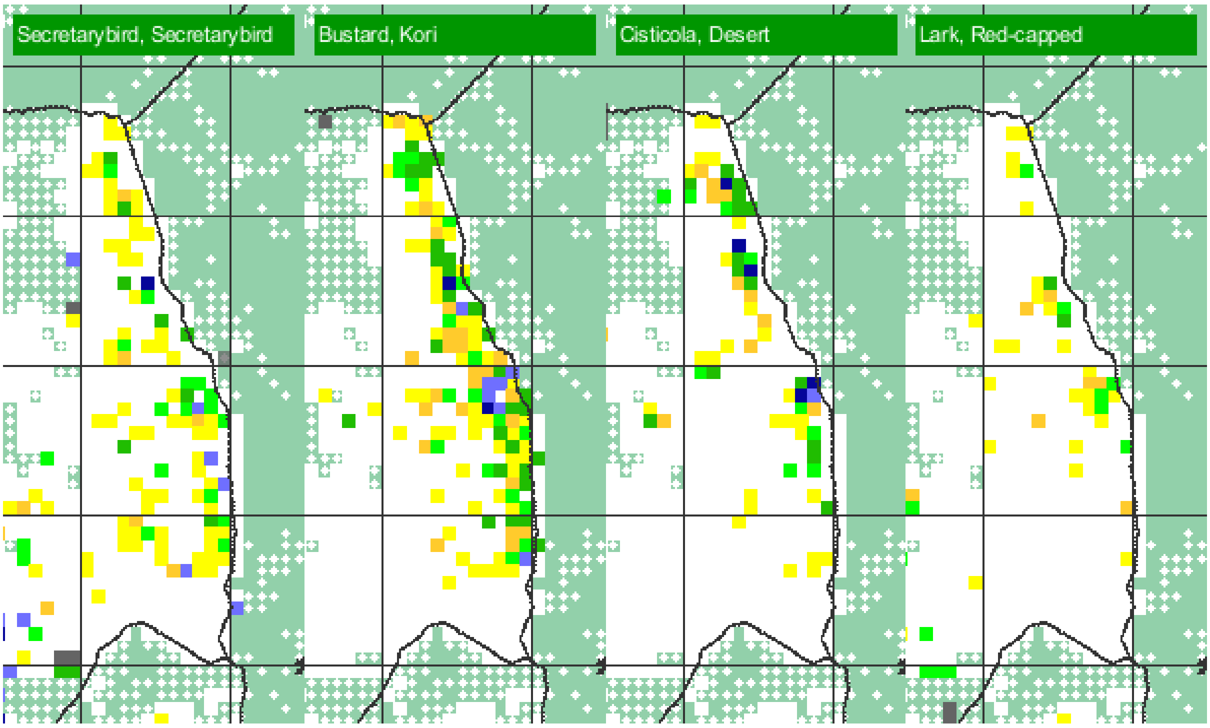

Figure 3.5 SABAP2 distributions of species within Group 13: Secretarybird, Kori Bustard, Desert Cisticola and Red-capped Lark.

Group 6 contains 17 species including Swainson's Spurfowl *Pternistis swainsonii* (303 pentads), Black-bellied Bustard *Lissotis melanogaster* (131), Flappet Lark *Mirafra rufocinnamomea* (147), and Magpie Shrike *Urolestes melanoleucus* (303 pentads) (Figure 3.6, Table 3.1). All the species in this group prefer open habitats, with an upper limit of about 20% or less woody cover. This is larger than that of the species in Group 13. These four species have been chosen for monitoring purposes; they occur in varying numbers of pentads (with 131 as minimum), they are taxonomically far apart and they all have upper limits of woody cover density of about 20%.

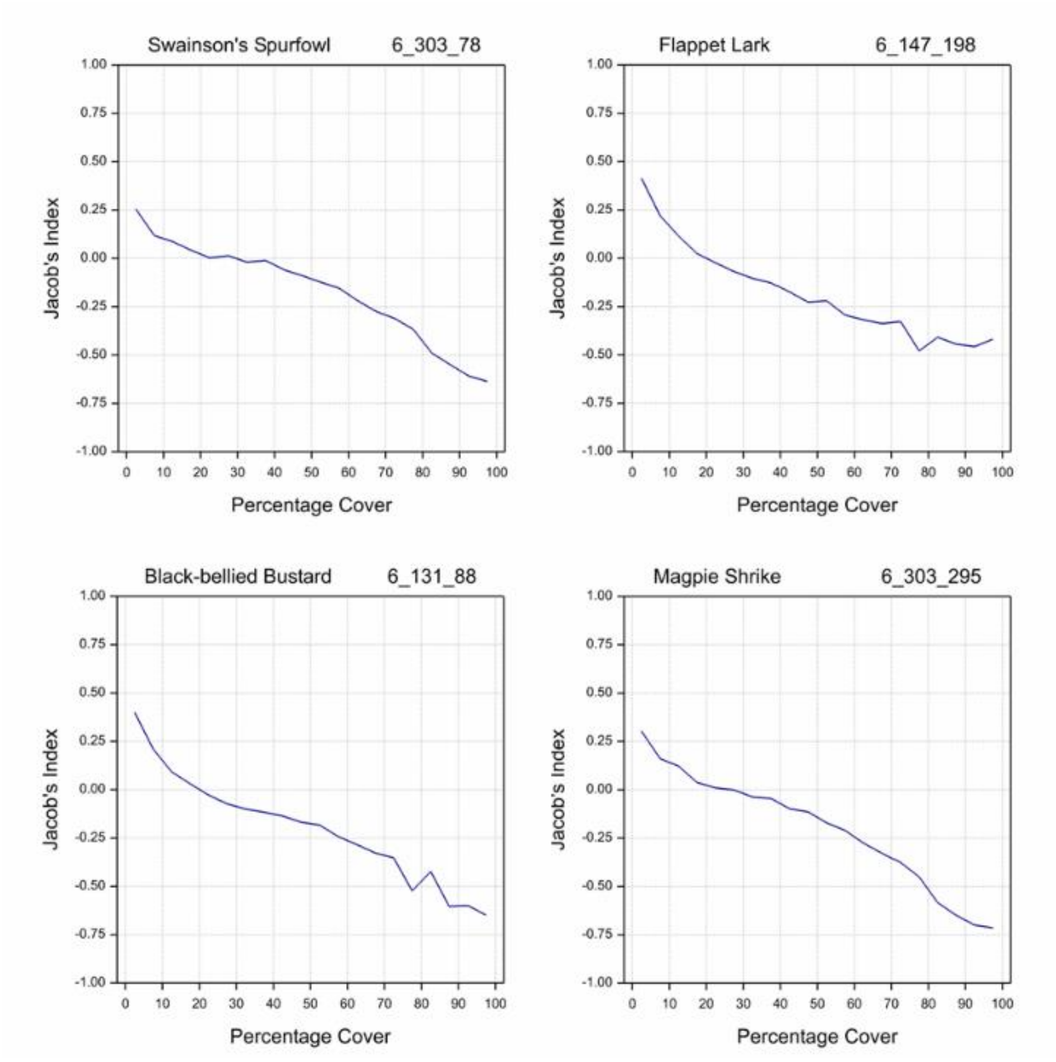

Figure 3.6 Percentage woody cover preference plots for Swainson's Spurfowl, Flappet Lark, Black-bellied Bustard and Magpie Shrike (Group 6).

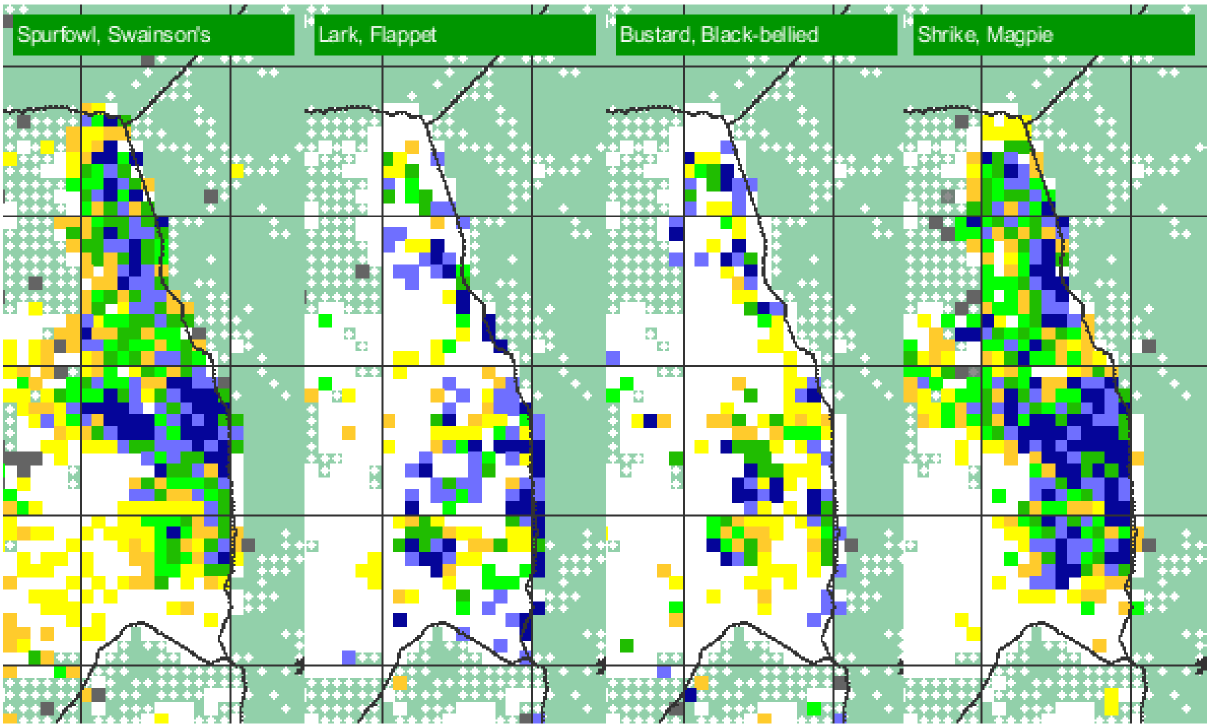

Figure 3.7 SABAP2 distributions of Group 6: Swainson's Spurfowl, Flappet Lark, Black-bellied Bustard and Magpie Shrike.

The 15 species in **Group 5** show a preference for habitats with a woody cover of between approximately 10–50% (Table 3.1, Figure 3.8). Most of the species in this group avoid areas without woody cover. Likewise, once the habitat becomes too wooded, at around 50% woody cover, preference decreases, and these species avoid dense woody cover. Group five includes Double-banded Sandgrouse *Pterocles bicinctus* (234 pentads), Southern Yellow-billed Hornbill *Tockus leucomelas* (357), Southern Ground Hornbill *Bucorvus leadbeateri* (217), and Dusky Lark *Pinarocorys nigricans* (105), which are the species selected from this group for monitoring. Species within this group have a woody cover preference of 10–50%. In other words, the monitoring ought to show that, if these species show shifts in range, new range is predicted to be grassland which has become lightly bush-encroached and range that is lost is predicted to be in areas where woody cover has increased to greater than 50%.

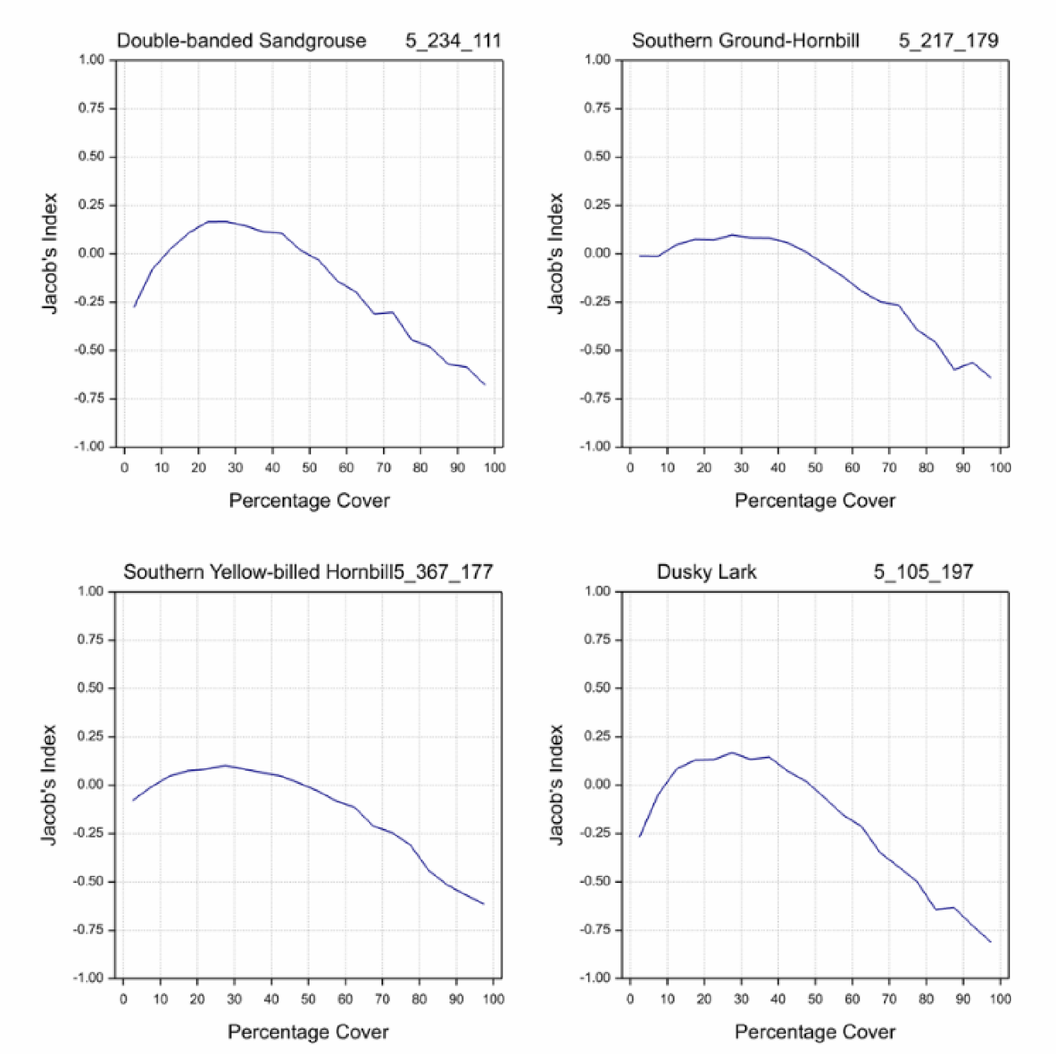

Figure 3.8 Percentage woody cover preference plots for Double-banded Sandgrouse, Southern Ground-Hornbill, Southern Yellow-billed Hornbill and Dusky Lark (Group 5).

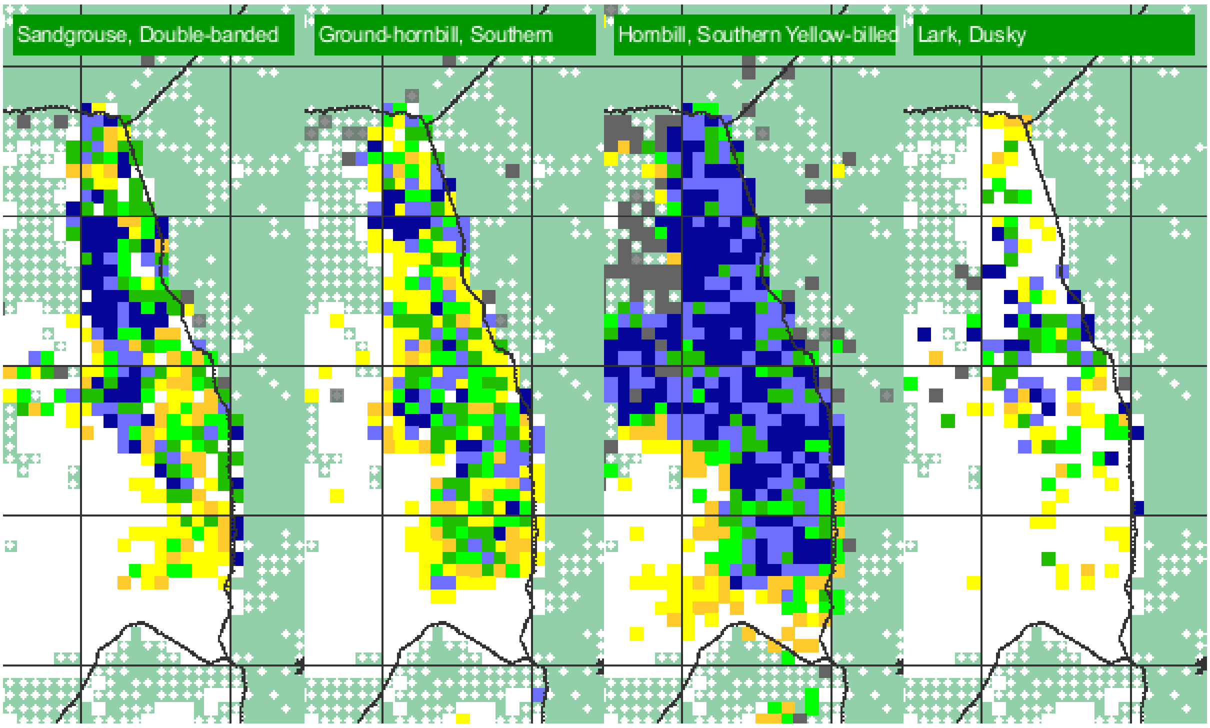

Figure 3.9 SABAP2 distributions of Group 5: Double-banded Sandgrouse, Southern Ground Hornbill, Southern Yellow-billed Hornbill and Dusky Lark.

The four species in **Group 15** (Figure 3.10) exhibit a preference for more wooded habitats. This group contains Crested Guineafowl *Guttera pucherani* (39 pentads), Broad-billed Roller *Eurystomus glaucurus* (55), Yellow-bellied Greenbul *Chlorocichla flaviventris* (98) and Tropical Boubou *Laniarius aethiopicus* (35). Species within this group prefer areas with a woody cover of 40–90% (Figure 3.10). Their core ranges within the KNP are in the north and north-eastern section of the park (Figure 3.11). This overlaps with the Sandveld vegetation zone (Figure 3.2). Of these four species, the Yellow-bellied Greenbul and the Broad-billed Roller are the choice of species for monitoring; the other two species are probably too range-restricted within the Kruger National Park to be appropriate choices. In relation to bush encroachment, the ranges of these species are anticipated to expand into regions where woody cover reaches 40%.

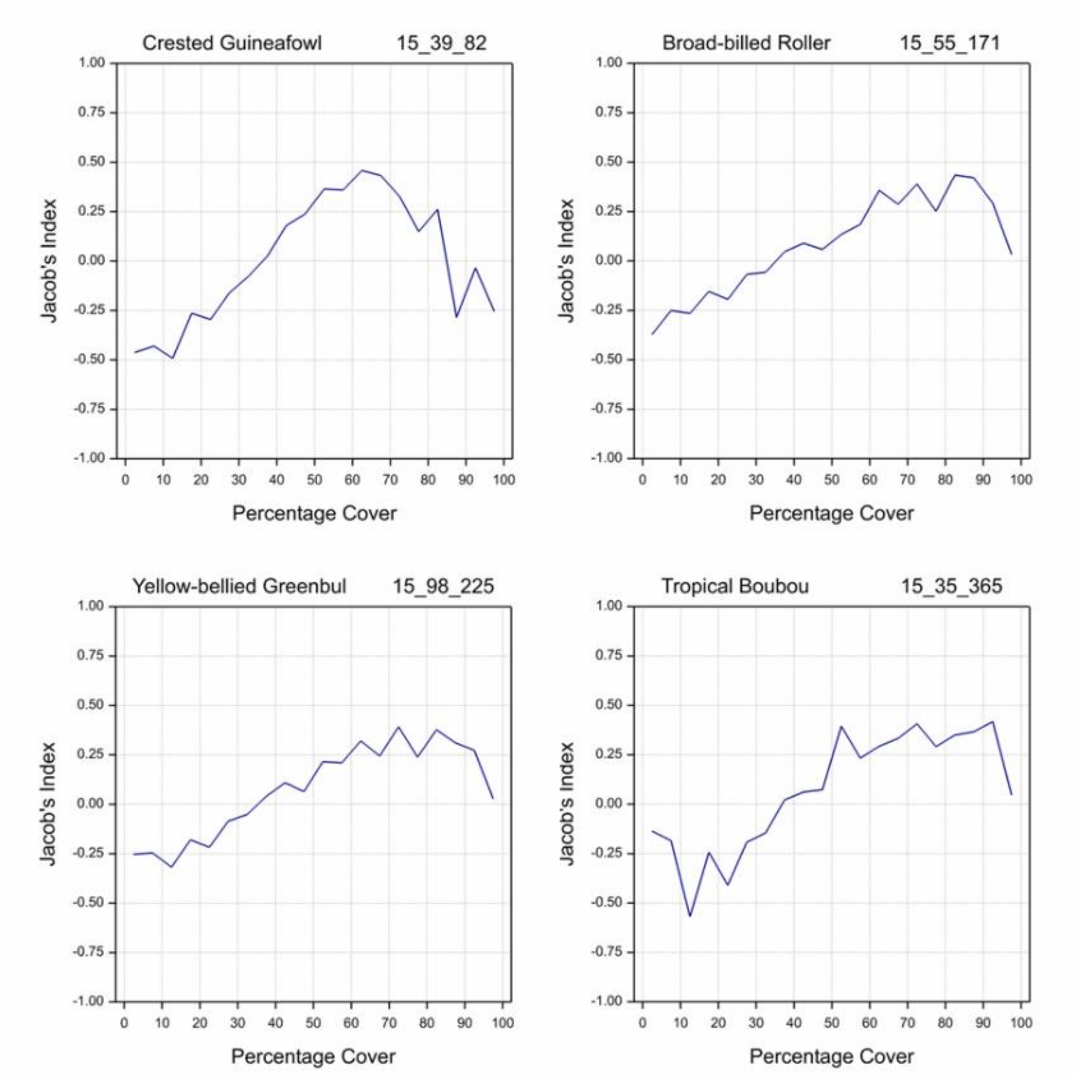

Figure 3.10 Percentage woody cover preference plots for Crested Guineafowl, Broad-billed Roller, Yellow-bellied Greenbul, and Tropical Boubou (Group 15).

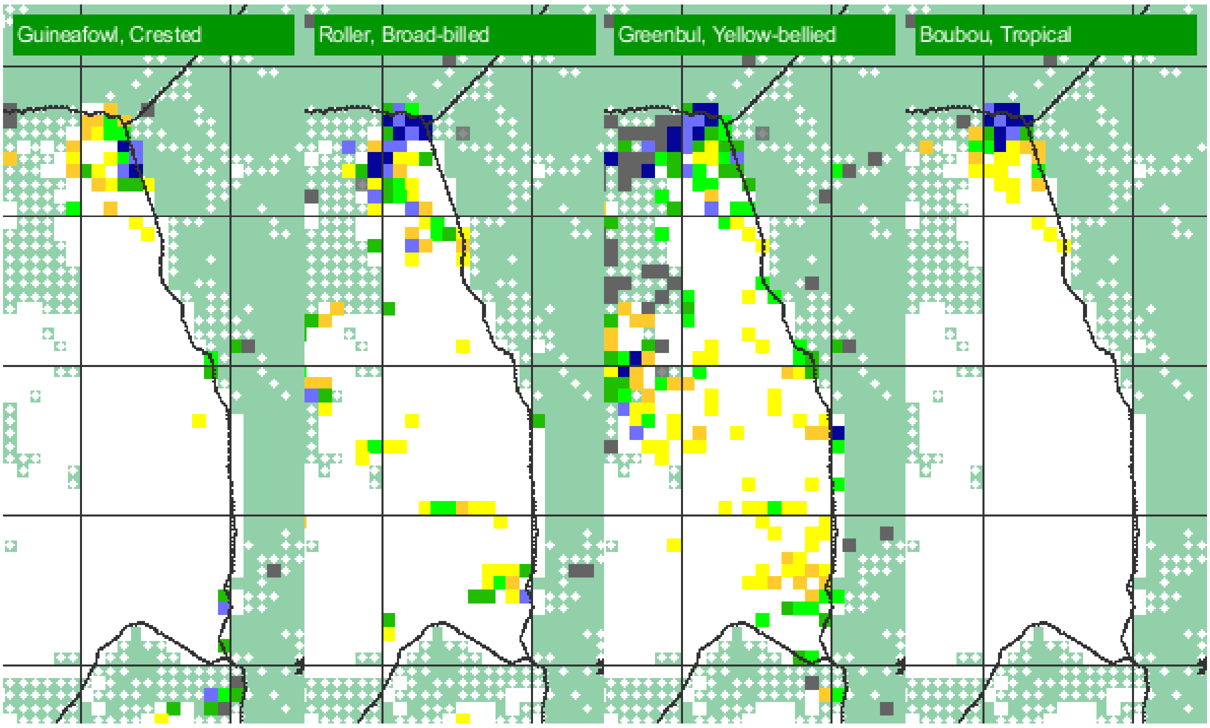

Figure 3.11 SABAP2 distributions of Group 15: Crested Guineafowl, Broad-billed Roller, Yellow-bellied Greenbul, and Tropical Boubou.

Group 22 is a large group containing 28 species (Table 3.1). They are all (except Familiar Chat *Cercomela familiaris*) characterized by having a single crossing of the zero preference line (Table 3.1) (Figure 3.12). In other words, they prefer dense woody cover, and for most of the species in the group the preference starts at 40% or 45% woody cover. Some of the species in Group 22 are Speckled Mousebird *Colius striatus* (266 pentads), White-browed Robin-Chat *Cossypha heuglini* (216), Green-backed Camaroptera *Camaroptera brachyura* (330), Yellow-breasted Apalis *Apalis flavida* (341), Village Weaver *Ploceus cucullatus* (226) and Spectacled Weaver *Ploceus ocularis* (296) (Table 3.1). The four species selected for monitoring are Speckled Mousebird, White-browed Robin-Chat, Green-backed Camaroptera and Yellow-breasted Apalis (Figure 3.12) (Figure 3.13). These species are expected to expand their ranges into areas where woody cover increases above 40% to 45%.

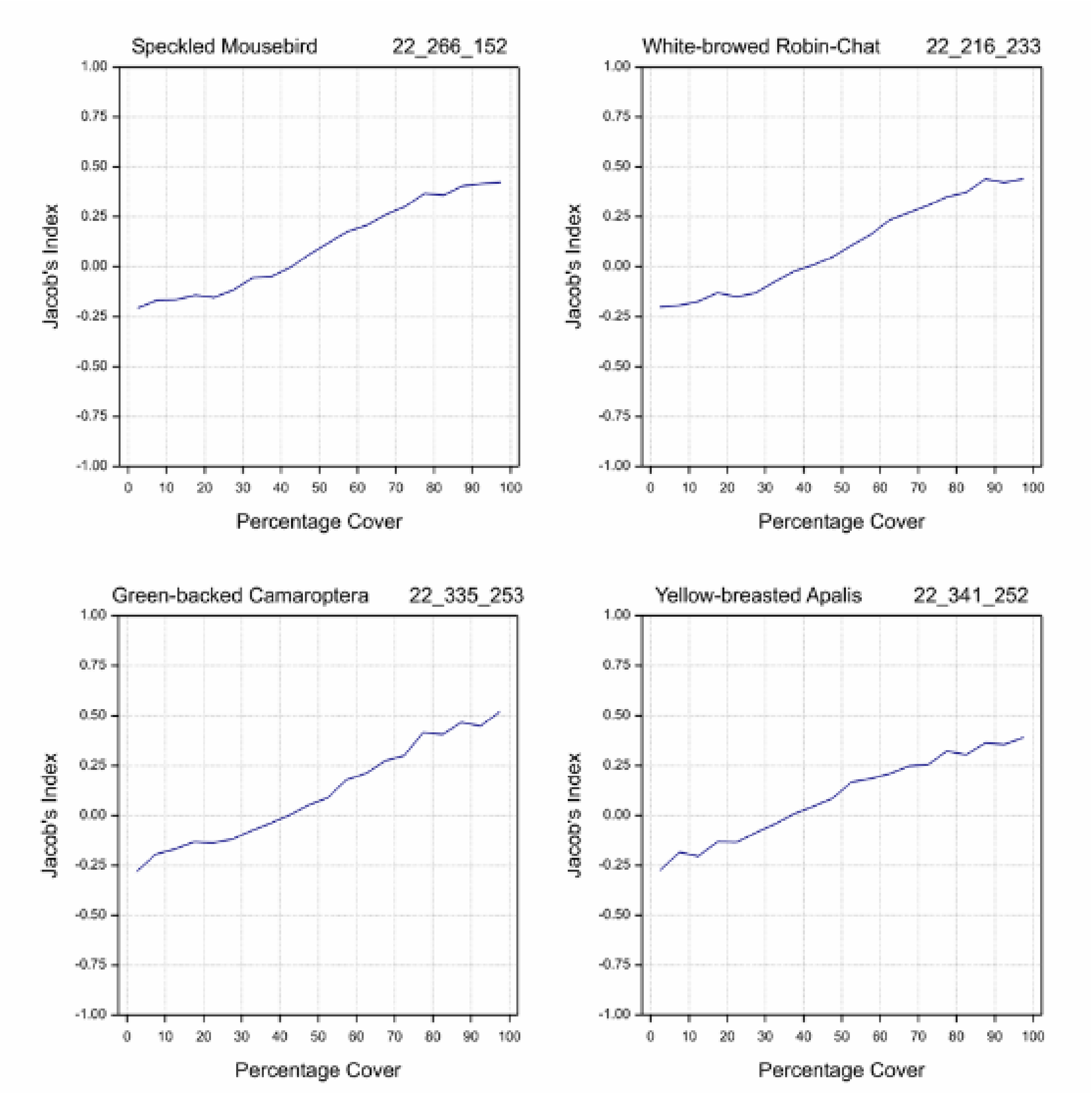

Figure 3.12 Percentage woody cover preference plots for Speckled Mousebird, White-browed Robin-Chat, Green-backed Camaroptera, Yellow-breasted Apalis (Group 22).

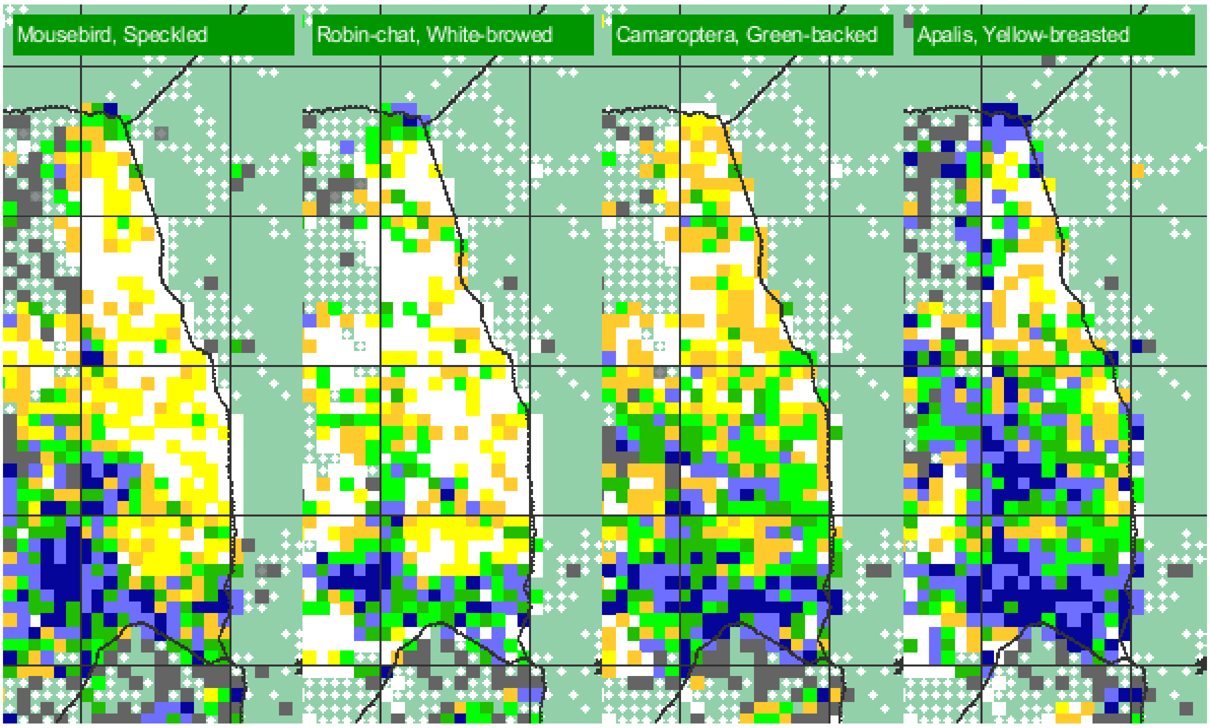

Figure 3.13 SABAP2 distributions of Group 22: Speckled Mousebird, White-browed Robin-Chat, Green-backed Camaroptera, Yellow-breasted Apalis.

Group 16 contains 25 species (Table 3.1). Sombre Greenbul *Andropadus importunus* (261 pentads), including Southern Boubou *Laniarius ferrugineus* (277), Gorgeous Bush-Shrike *Chlorophoneus viridis*, (126) and African Firefinch *Lagonosticta rubricata* (212). This group prefers habitats with a woody cover greater than 40% (Figure 3.14). These are the four species selected for monitoring purposes.

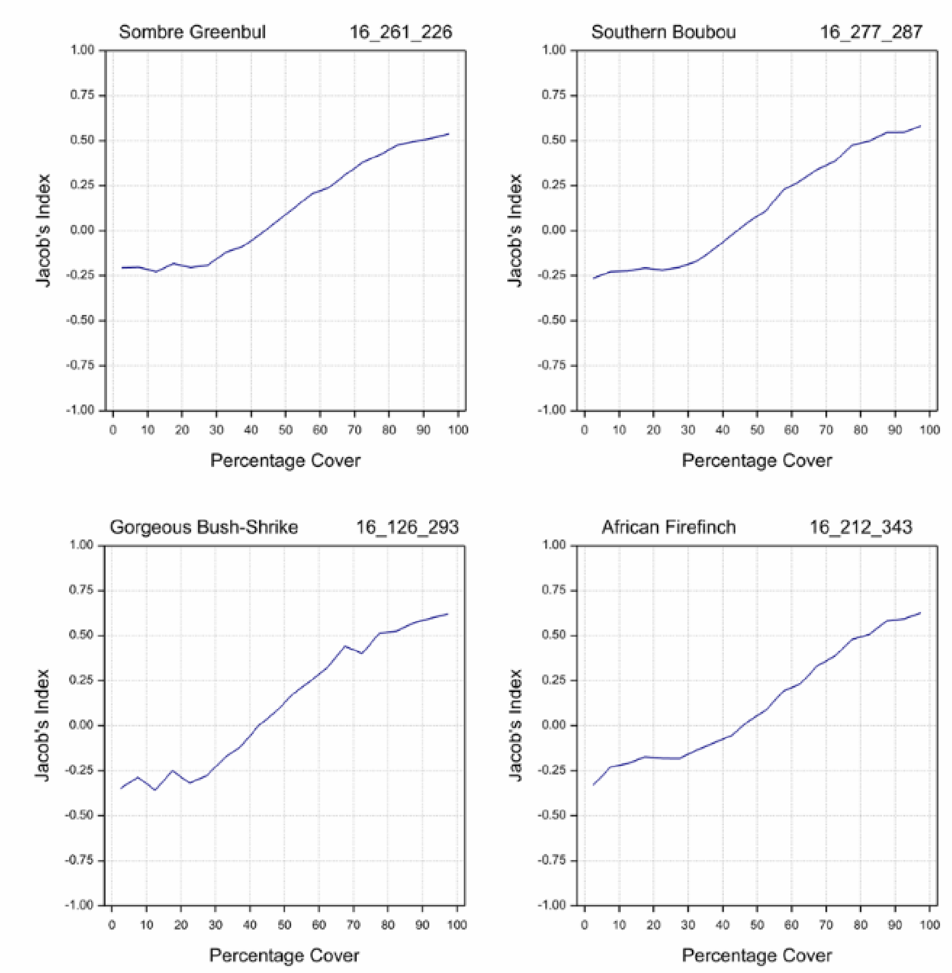

Figure 3.14 Percentage woody cover preference plots for Sombre Greenbul, Southern Boubou, Gorgeous Bush-Shrike, African Firefinch (Group 16).

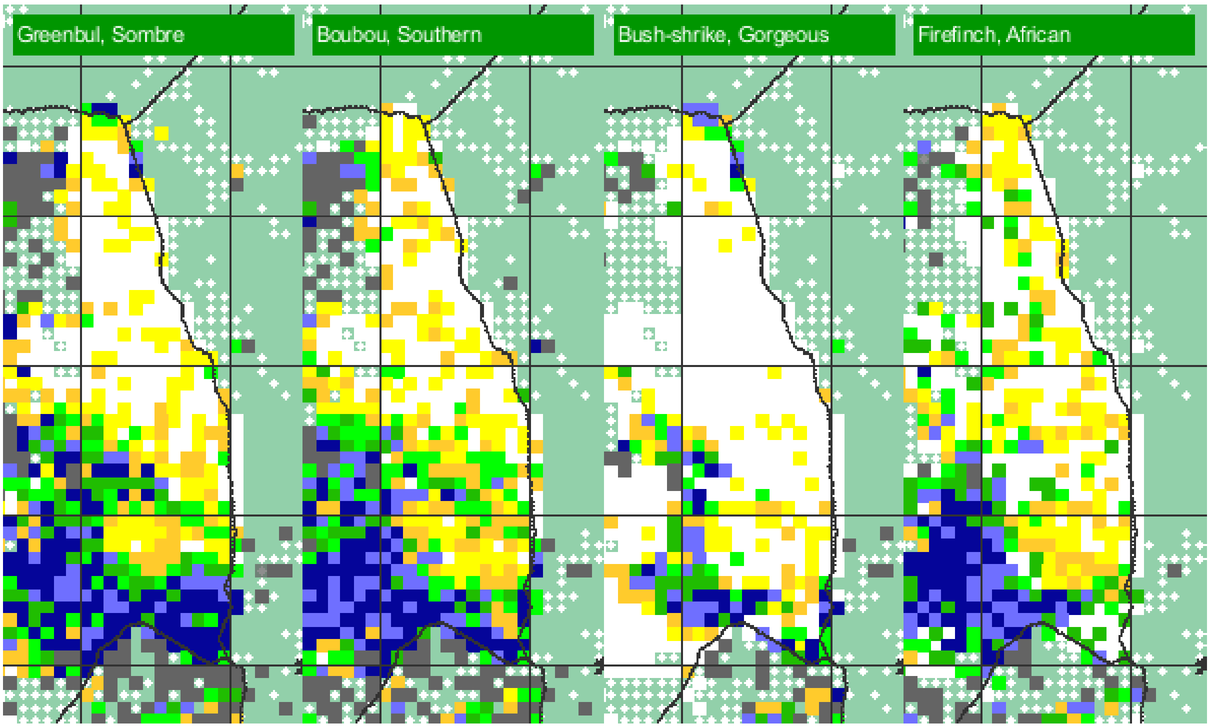

Figure 3.15 SABAP2 distributions of Group 16: Sombre Greenbul, Southern Boubou, Gorgeous Bush-Shrike, African Firefinch.

Group 19 includes the 27 species with the strongest preferences for dense woody cover (Figure 3.16). For most of these species the preference for the 95–100% woody cover class had a Jacobs' Index exceeding 0.7 (Table 3.1). Overall, they have a preference for habitats with woody cover exceeding 50% (Figure 3.16). The four species in this group recommended for monitoring purposes are Cape White-eye *Zosterops virens* (158 pentads), Bar-throated Apalis *Apalis thoracica* (119), Red-capped Robin-Chat *Cossypha natalensis* (122) and Amethyst Sunbird *Chalcomitra amethystina* (160). 19 of the 27 species in this group are small passerines, most of them have a small body size and none are in threat categories.

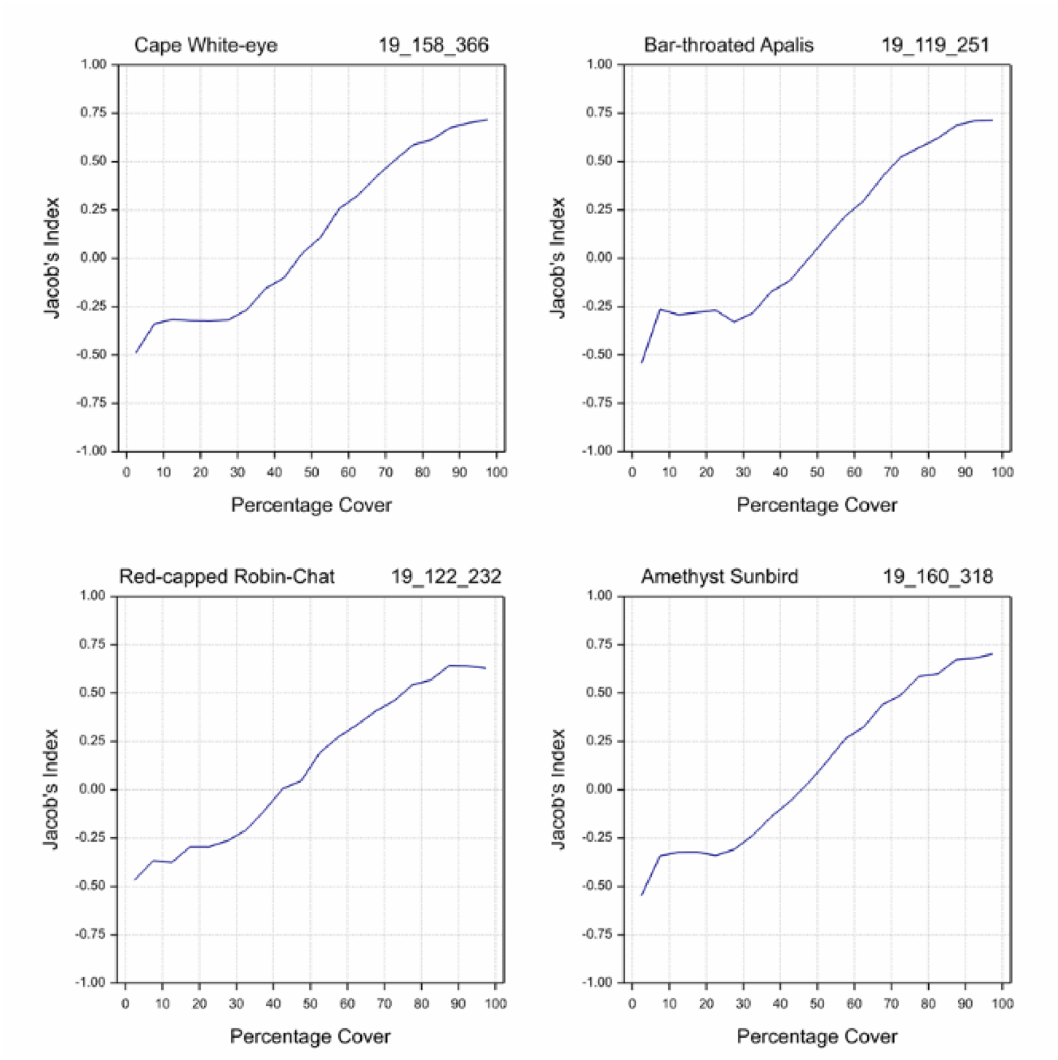

Figure 3.16 Percentage woody cover preference plots for Cape White-eye, Bar-throated Apalis, Red-capped Robin-Chat and Amethyst Sunbird (Group 19).

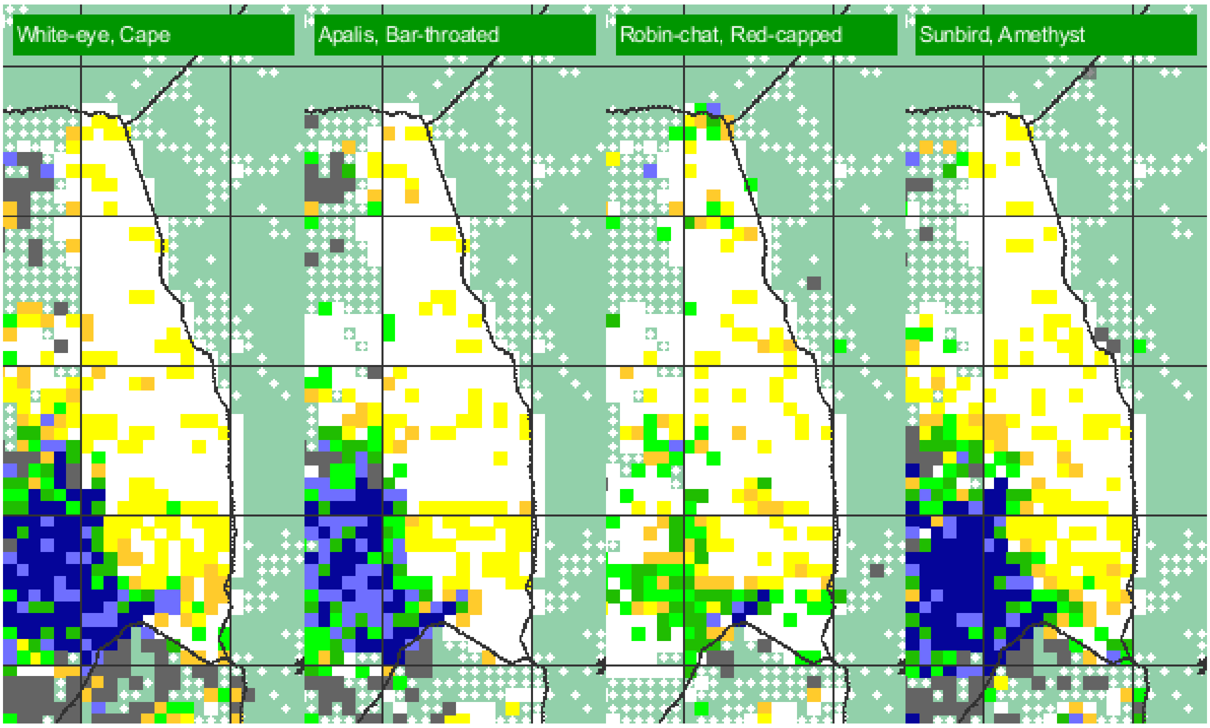

Figure 3.17 SABAP2 distributions of four species in Group 19: Cape White-eye, Bar-throated Apalis, Red-capped Robin-Chat and Amethyst Sunbird.

Discussion

Candidate bird species for monitoring bush encroachment

The primary goal of this chapter has been achieved. Twenty-eight bird species have been selected which have the potential to assist with the broad-brush monitoring of bush encroachment in the Kruger National Park. This goal has been realized through an algorithm, developed experimentally in Chapter 2, and applied here to achieve a specific purpose.

The actual implementation of the monitoring is beyond the scope of this chapter. The concept that needs to be considered is predicated on the continuation of the SABAP2 protocol continuously into the future, and the strong encouragement to citizen scientists to continue undertaking bird atlas fieldwork in the Kruger National Park. Range-change maps, using the same strategy as developed by Underhill and Brooks (2016) and applied in Chapter 4, need to be implemented on a pentad scale, and need to split the SABAP2 data into two (or more) time periods. Changes in distribution of the monitoring species would then point to changes in woody cover.

It is predicted that species in the same group would show broadly similar ranges (but see the section below entitled *Birds and tree species composition*). For example, decreases in the ranges of the selected species from Group 13 (the grassland-preference species shaded yellow in Table 3.1) would indicate loss of grassland habitats and help point to where this loss had occurred. Similarly, increases in the ranges of Group 19 species (the thick woodland preference species shaded brown in Table 3.1) would help point to where woody cover was approaching closed canopy levels. Range changes for species in Group 5 (shaded green in Table 3.1) are predicted to be more complex. Woody cover most preferred by these species is at a level of about 30% (Figure 3.8). Areas which had 30% woody cover in the period of the first split of the SABAP2 data would be predicted to have the largest reporting rates for the selected Group 5 species. Shifts in core of the distributions of these bird species, as indicated by areas with highest reporting rates, are predicted to point to shifts in the area with 30% woody cover.

Woody cover determinants in the Kruger National Park

The Kruger National Park is, mainly on account of its size, regarded as one of South Africa's most important protected areas for the long-term conservation of biodiversity (see Study Area above). For example, in the 2000 edition of the Red Data Book for Birds (Barnes 2000), it was stated for several species that, in spite of decreases in unprotected areas, it would be conserved for posterity in the Kruger National Park (e.g. Secretarybird, Martial Eagle). However, SABAP2 revealed that this paradigm was incorrect and that large decreases in these two iconic species had occurred in the Kruger National Park, and that this was linked to habitat change, especially to changes in woody cover (Hofmeyr et al. 2014, Amar et al. 2015). Thus understanding why woody cover has changed drastically in a protected area such as the Kruger National Park is of great importance to biodiversity conservation there.

The amount of woody vegetation throughout the park is influenced by a range of local and global factors; fire and herbivory being some of the main local factors (Sankaran et al. 2005, Accatino et al. 2010). Fire causes physical damage, sometimes mortality, to woody vegetation and these effects can vary depending on the timing, intensity and frequency of fires (Skarpe 1991). Fire can help to keep woody vegetation densities in check, but only if fires are frequent enough when related to the growth rates of woody plants (Skarpe 1991). Herbivores, and more specifically browsers like Elephants, Kudu *Tragelaphus strepsiceros*, Giraffe *Giraffa giraffa giraffa*, Black Rhino *Diceros bicornis*, Common Duiker *Sylvicapra grimmia*, Nyala *Tragelaphus angasii* and Bushbuck *Tragelaphus* *scriptus* affect the height, density, composition, canopy size and stem diameter of woody plants (Levick and Rogers 2008; Wigley et al. 2014). Elephants are thought to have the biggest impact on woody vegetation (Munyati and Sinthumule 2016).

Buitenwerf et al. (2012) conducted a study in the KNP and Eastern Cape Province of South Africa to determine how big the impacts of global drivers, like increased carbon dioxide levels in the atmosphere, have been on woody vegetation in the past 50 years. In the KNP, they analysed data from two sites (about 100 km apart) with contrasting climates and soils. The one site was near Satara Camp, central KNP. This is a semiarid savanna area with a mean annual precipitation of 537 mm, mainly basaltic clay soils, and woody vegetation dominated by Knobthorns and Sickle Bush (Buitenwerf et al. 2012). The other site was located in the south of the park near Pretoriuskop. This area is a mesic savanna area with a mean annual precipitation of 737 mm, sandy granitic soils, and woody vegetation dominated by Silver Cluster Leaf and Sickle Bush (Buitenwerf et al. 2012). The results showed that at the semiarid site there have been some increases in woody vegetation, but not significantly so, but at the mesic site woody vegetation has seen a threefold increase between the 1970's and 1990's (Buitenwerf et al. 2012). Increased carbon dioxide concentrations in the atmosphere were found to be consistent with the increased densities in woody vegetation while other drivers, like rainfall and fire, remained constant over the duration of the experiments (Buitenwerf et al. 2012).

Sickle Bush trees/shrubs have the ability to quickly colonize disturbed areas and help to curb erosion, but they are known to be an encroacher species and can form impenetrable thickets which can become a problem for conservation and land managers (Ross 1975). They are nitrogen-fixing legumes though and have a positive effect on the soil nitrogen content (Ross 1975).

Birds and tree species composition

Clearly, not all bird species have distributions which are determined by woody cover, but the remarkable outcome of this chapter is that many species have tight preferences for relatively narrow woody cover ranges. The distributions of many species (especially those in the 16 "interior" groups of Figure 3.3), depend on factors other than tree cover, or only depend to a limited extent on tree cover.

In addition, there are bird species which have preferences for particular tree species composition, so that not only does the woody cover need to be appropriate for the bird species, but the tree species composition needs to be correct as well.

These tree preference factors also need to be considered in selecting bird species for the monitoring of woody cover.

For example, in Mopane woodland or Mopaneveld areas the tree species composition consists of not only of Mopane but includes Russet Bushwillow *Combretum hereroense*, Knobthorn, and Apple-leaf *Philenoptera violacea.* Tambotis *Spirostachys africana* and Leadwoods along the drainage lines in Mopaneveld. Certain bird species are associated with this mix of trees, such as Southern Yellow-billed Hornbill and Racket-tailed Roller *Coracias spatulatus* (Chittenden and Whyte 2008).

Bird species such as the Trumpeter Hornbill *Bycanistes bucinator* prefer areas with tall trees and therefore they are usually restricted to riverine forest (del Hoyo et al. 2001). In the KNP, they are often found in the Levuvhu River area in the north and they have been recorded along the Olifants, Sabie and Crocodile Rivers too (Chittenden and Whyte 2008).

In the grassland areas of the park game birds are plentiful, these include birds such as Shelley's Francolin *Scleroptila shelleyi*, Coqui Francolin *Peliperdix coqui*, and the Harlequin Quail *Coturnix delegorguei* (BirdLife South Africa 2016). The grasslands also support some of the largest birds in the KNP, such as the Common Ostrich *Struthio camelus*, Secretarybird and Kori Bustard. Many of the seed-eating birds such as the Sabota Lark *Mirafra sabota* and other larks, some cisticolas and buntings can be found here, as well as the more omnivorous Lilac-breasted Rollers and Magpie Shrikes that like to forage in open savanna and woodland clearings (Chittenden and Whyte 2008).

The thicket and forest areas in the KNP support birds such as the Brown-headed Parrot *Poicephalus cryptoxanthus* and Gorgeous Bush-Shrike (BirdLife South Africa 2016). Brown-headed Parrots prefer habitats with fruit or seed-bearing trees like Knobthorns and Mopane trees (Hockey et al. 2005). Gorgeous Bush-Shrikes prefer woodland habitats with dense undergrowth and they can be found along forest edges too (Hockey et al. 2005). In the sandveld habitats in the north-east of KNP Pink-throated Twinspots *Hypargos margaritatus* occur, they prefer woodlands with dense undergrowth and thick scrubland, as well as species such as Yellow-bellied Greenbuls and Tropical Boubous (Figure 3.11) (BirdLife South Africa 2016). In the north-east there is also a type of savanna known as Lala Palm *Hyphaene coriacea* savanna, here one can find species such as the Lemon-breasted Canary (BirdLife South Africa 2016). Lemon-breasted Canaries use Lala Palms as nesting sites and they make their nests from Lala Palm plant fibres, therefore their distribution is quite strongly linked to Lala Palms (Hockey et al. 2005).

Other applications for the woody cover preference plots

These quantitative woody cover preference plots are the first of their kind to be produced. They could prove invaluable for the management plans of individual species in the KNP. They provide guidance to management as to the precise woody cover targets which need to be maintained to protect a particular species. Examples of species for which these plots could prove to be a useful management tool to protect and create habitats for sensitive species include Southern Ground Hornbill, Secretarybird and Kori Bustard. These are species for which quantitative woody cover targets are now available.

The woody cover preference plots for species are simple to interpret. The preferred woody cover categories are where the signature line for the species is most positive. They could readily be included in field guides and in handbooks, and especially for species in the seven groups along the "arch" of Figure 3.3.

The algorithm could be used to search for areas in which to create protected areas for particular savanna species. For example, armed with the knowledge that the signature for Southern Ground Hornbill peaks at woody cover values of about 30% (Figure 3.8), this information could guide the selection of potential protected areas for this species.

Recommendations for further research

The quantitative woody cover preferences, presented as "signatures", which have been generated in this chapter, and in Chapter 2, coincide remarkably well with qualitative judgement. Although this indicates, in broad terms, that the algorithm developed in this thesis works, it still needs to be formally ground-truthed by fieldwork. This fieldwork would preferably be done using the same 25-hectare pixels as the LiDAR data.

Guidance as to the feasibility of this approach to monitoring changes in woody cover could be assessed by dividing the existing SABAP2 data into two time periods. One decade of fieldwork could split into two five-year periods, and changes in the distributions of the species selected for monitoring could be compared. But one decade of SABAP2 fieldwork (starting mid-2007) might prove to be too short a period to give the approach a fair test. Because of the change in protocol between SABAP1 and SABAP2, it would probably be unwise to expect meaningful fine-scale results from a comparison of the two bird atlases, even though they are almost a quarter century apart. Maintaining the SABAP2 protocol (Underhill et al. 2017) into the future is critical for the success of this approach to monitoring changes in bush encroachment, as measured by woody coverage.

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Appendix 3.A Background biological information on the 28 species selected as candidate species for assisting with the monitoring of bush encroachment in the Kruger National Park.

Group 13

Secretarybirds prefer grassland habitats and open savanna scattered with thorn trees such as *Vachellia* spp. (Ferguson-Lees and Christie 2001). They prefer areas where the groundcover is shorter than 50 cm (Dean and Simmons 2005). They also inhabit farming areas (particularly cereal croplands), open clearings in woodlands and semi-desert areas. Secretarybirds avoid dense woodlands, thickets, forests, as well as mountainous, rocky or hilly areas (Boshoff and Allan 1997). This is clearly displayed by its woody cover preference plot (Figure 3.4). Bush encroachment is very likely to have a negative impact on Secretarybirds.

Globally, Secretarybirds are in decline, they are classified as Vulnerable on the IUCN Red List (BirdLife International 2016b). Their population has declined by more than 30% in the past 10 years (Taylor et al. 2015). Hofmeyr et al. (2014) found that the Secretarybird has declined significantly in the KNP. It shows significant declines in more than 70% of the QDGCs it occurs in since SABAP1. Bush encroachment has also rendered habitat unsuitable for Secretarybirds in Swaziland (Parker 1994). Collisions with powerlines and wind turbines also pose a threat (Taylor et al. 2015). A land management policy to manage bush encroachment is recommended. Taylor at al. (2015) suggests involving landowners and local communities in an awareness campaign highlighting the threats faced by Secretarybirds.

Kori Bustards prefer open savanna and grassy habitats (Hockey et al. 2005). Kori Bustards are listed as Near Threatened on the IUCN Red List (BirdLife International 2016a). It is thought that the reasons for its population decline is due to habitat loss which is linked to rangeland degradation and bush encroachment (Senyatso et al. 2012). In the lowland areas of Swaziland bush encroachment and hunting has resulted in local extinctions (Taylor et al. 2015).

Desert Cisticolas prefer grassland areas, especially habitats with *Stipagrostis* grass (Hockey et al. 2005). They also occur in grassy areas with some scattered trees and bushes, which means that areas that have too much woody cover would be avoided.

Red–capped Larks are common and can be quite abundant in open grassland habitats (Hockey et al. 2005). They also favour recently burnt, cultivated, or harvested fields in farmland areas. They are often observed along road verges after rainfall. During SABAP1 it had the highest reporting rates in sweetveld grasslands and mixed grasslands (Dean 1997b). Red-capped larks like to forage for insects and seeds on bare ground or in very short grass. Bush encroachment would limit their foraging efforts.

Group 6

Swainson's Spurfowl occurs in grasslands or open savannas (Hockey et al. 2005). Black–bellied Bustards are more common in grassy habitats, which includes dense grassland and grassy savanna (Hockey et al. 2005). They are listed as Near Threatened in South Africa and Swaziland since 2000 due to habitat destruction and overgrazing, which is a contributing factor to bush encroachment (Taylor et al. 2015).

Flappet Larks favour grassy clearings and the open stretches within drainage lines within broad-leaved woodland, they also occupy coastal grassland and open savanna (Hockey et al. 2005).

Magpie Shrikes prefer open savanna woodland with short grass clumps and some bare ground (Hockey et al. 2005). Magpie Shrikes like to perch on trees or bushes from where they search the surroundings for prey (insects and other invertebrates), and when something is spotted they dive down to the ground to catch it (Hockey et al. 2005). If the habitat has too much woody cover, it could become difficult for birds that use the "perch and scan" method to spot and catch their prey.

Group 5

The Double-banded Sandgrouse generally prefers open Mopane woodland, but they are found in *Vachellia* and *Senegalia* savanna too (van Niekerk 2012).

The Southern Ground Hornbill is a sedentary species in the KNP. They reside throughout the year in cohesive groups, of 2–11 members, within exclusive territories (Kemp et al. 1989). Southern Ground Hornbills forage on the ground, preying on a wide range of invertebrates (insects, scorpions, spiders) and small vertebrates (like frogs, lizards, and mice) (Kemp 2005). They need open habitats and fairly open understories in savanna and woodland areas to locate their prey (Cilliers et al. 2013). Afforestation of grasslands, thickening of woodlands and bush encroachment in savannas pose a major threat to Southern Ground Hornbills as it prevents them from foraging successfully (Cilliers et al. 2013). BirdLife South Africa (2016) has also assessed that the thickening of woody vegetation, and an increase in bush encroachment, is a serious threat to many of the Important Bird Areas (IBA) trigger species, particularly ground-living birds such as Southern Ground-Hornbills and Secretarybirds. Trigger species are defined as species that help to justify the proclamation of an IBA. They are usually IUCN Red Listed species. Species that fall into globally threatened categories that occur in the KNP are the Cape Vulture *Gyps coprotheres*, Southern Ground-Hornbill, Hooded Vulture *Necrosyrtes monachus*, White-backed Vulture *Gyps africanus*, Lappet-faced Vulture *Torgos tracheliotos*, White-headed Vulture *Trigonoceps occipitalis*, Kori Bustard (Near Threatened), Crowned Eagle *Stephanoaetus coronatus*, Bateleur *Terathopius ecaudatus*, Secretarybird and Martial Eagle *Polemaetus bellicosus*. There are also regionally threatened species that occur in the KNP, these include White-backed Night Heron *Gorsachius leuconotus*, Saddle-billed Stork *Ephippiorhynchus senegalensis*, Tawny Eagle *Aquila rapax*, African Finfoot *Podica senegalensis*, African Grass Owl *Tyto capensis*, Pel's Fishing Owl *Scotopelia peli*, Black Stork *Ciconia nigra*, Marabou Stork *Leptoptilos crumenifer*, African Pygmy Goose *Nettapus auritus*, Bat Hawk *Macheiramphus alcinus*, Lanner Falcon *Falco biarmicus*, Greater Painted Snipe *Rostratula benghalensis*, Half-collared Kingfisher *Alcedo semitorquata* and Lemon-breasted Canary *Serinus citrinipectus*.

Yellow-billed Hornbills are near-endemic to southern Africa (Hockey et al. 2005). In general, they prefer dry, open *Vachellia* and broad-leaved savannas. They do occur in many other wooded vegetation types, but preferably the ground cover should be sparse enough and not too thick/tangled as it does most of its foraging on the ground (Hockey et al 2005). Yellow-billed Hornbills can be seen as a “precursor to bush encroachment” species. Their recent range expansion into the Kalahari savanna regions of the eastern Northern Cape Province suggests the onset of bush encroachment (Figure 3.18)

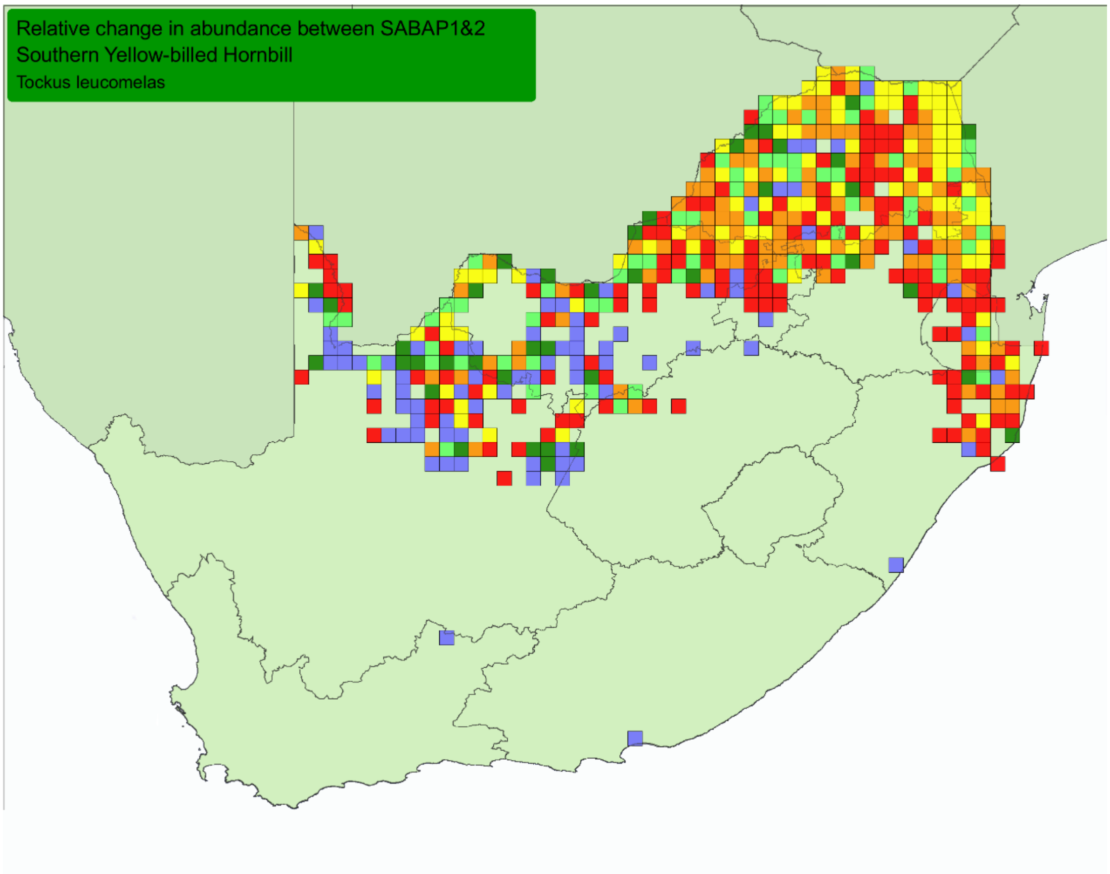

Figure 3.18 Changes in abundance between SABAP1 and 2 for Yellow-billed Hornbill.

Dusky Larks prefer mesic and semi-arid savanna as well as woodland. They like grassy patches in mixed Bushwillow woodland or Mopane woodland (Hockey et al. 2005).

Group 15

Crested Guineafowls favour forest edges, thickets and dense woodland (Hockey et al 2005). The SABAP1 vegetation analysis showed that highest reporting rates were recorded in forest and woodland habitats (Little 1997).

Broad-billed Rollers generally prefer savanna and clearings in woodlands. They can be found in any well-developed woodland or riparian forest, especially along the Limpopo River (Tree 1997).

Yellow-bellied Greenbul generally prefers thick tangled undergrowth, it favours riverine and coastal forest, and shrubs and thickets on and around termite mounds in woodland areas such as miombo and mopane (Oatley 1997). It can also be found in gardens, mangroves and semi-arid bush (Hockey et al. 2005).

Tropical Boubous occur in habitats that have dense undergrowth and tangled vegetation. They prefer riparian woodland and thorn thickets (Parker 1997). Tropical Boubous also occupy montane forest, suburban gardens, thick coastal scrub, savanna and miombo woodland (Hockey et al. 2005). They are common breeding residents along the Limpopo River in South Africa where they occur in riverine thickets and dense woodland (Taylor et al. 2015). They are considered a peripheral species in South Africa, but it appears that Tropical Boubous have increased in abundance and expanded their range in South Africa (Taylor et al. 2015).

Group 22

Speckled Mousebirds are very adaptable. They occur along forest edges, in thickets, gardens, orchards, riverine woodlands and even in alien tree plantations (Hockey et al 2005). They are frugivores and feed on a broad range of plant matter including leaves, flowers, nectar, fruits and buds (Hockey et al. 2005). They eat the leaves of *Vachellia* and *Senegalia* spp. as well as the leaves of the Scrambling Senecio *Senecio pleistocephalus.* The Scrambling Senecio is quite an aggressive climber and scrambler in bush and scrub habitats (Bandeira et al. 2007). It occurs in the in bushveld, woodland and hillside scrub areas of north-eastern South Africa (Bandeira et al. 2007). It is associated with bush encroachment.

White-browed Robin-Chats favour riverine forest and dense evergreen thickets. It mainly eats insects, doing most of its foraging on the ground, flicking through leaf litter in search of prey and occasionally gleaning food from foliage and tree trunks (Hockey et al. 2005).

The Green-backed Camaroptera is a member of the Cisticolidae family. Loftie-Eaton (2014) found that the Cisticolidae family as a whole has increased in abundance significantly since SABAP1. The mean probability of increased reporting rates in any cisticola species' range was 64.2% (Loftie-Eaton 2014). Green-backed Camaropteras generally prefer riverine woodland savanna woodland, they also occur along forest edges, and can be found in gardens and parks too (Hockey et al. 2005).

The Yellow-breasted Apalis favours riverine woodland, evergreen forest, Mopane woodland and *Vachellia* woodland (Hockey et al. 2005).

Group 16

The Sombre Greenbul prefers forest and well-wooded valleys, as well as coastal scrub (Hockey et al. 2005). It also occupies thornveld, dry woodland thickets along drainage lines in the Karoo and gardens in well-wooded suburbs.

The Southern Boubou favours a variety of woodland habitats, as well as coastal thickets, riverine scrub, alien tree plantations and suburban gardens (Hockey et al. 2005).

Gorgeous Bush-Shrikes favours woodlands with dense undergrowth, especially riparian woodland (Hockey et al. 2005). It also occurs in wooded drainage lines in thornveld, forest fringes, dune forest and coastal evergreen forest patches (Hockey et al. 2005).

The African Firefinch generally prefers moist, densely vegetated habitats such as bracken *Pteridium aquilinum* at the edge of forest and rank grass with tangled undergrowth along watercourses (Hockey et al. 2005). They are also often found in gardens and rural villages.

Group 19

Cape White-eyes are very common in a wide variety of habitats. They occur in evergreen forest, *Vachellia* woodland, gardens and parks, coastal forest, and Eucalyptus plantations (Hockey et al. 2005). They will make use of wooded habitats in more grassy habitats (Nuttall 1997).

The Bar-throated Apalis is very adaptable and can be found in a wide variety of wooded habitats (Day 1997). They occur in evergreen forests, along forest fringes and woodland. They may also occur in areas where sufficient amounts of woodland or bush occurs (Day 1997). Bush encroachment and bush thickening would surely benefit the Bar-throated Apalis. They like foraging for insects in dense vegetation (Day 1997).

Red-capped Robin-Chats occur in evergreen forests along watercourses, bushveld riparian thickets, dune forests along the coast, well-wooded suburban gardens and they have been observed in banana plantations too (Hockey et al. 2005). They have been observed in miombo woodland and hillside drainage lines in river valley bushveld as well (Hockey et al. 2005)

Amethyst Sunbirds prefer coastal evergreen forests and mature valley bushveld (Hockey at al. 2005). They do, however, also move into drier, more open woodland and they have been observed to fly some distance to reach clumps of nectar-baring plants like Aloes (Hockey et al. 2005).

CHAPTER 4

Range Changes of Palearctic Migrant Birds in Southern Africa over Two Decades

Introduction

In 1990, the German ornithologist, Peter Berthold presented a paper at the 20th International Ornithological Congress in New Zealand on the topic of long distance bird migration; since that date, there has been a strong realisation that long distance bird migration is likely to be particularly vulnerable to climate change (Berthold 1991). Over western and central Europe, the broad-brush pattern conforms with Berthold's (1991) prediction, and the species with the largest decreases in abundance are the long-distance migrants (Gregory et al. 2007, Jørgensen et al. 2015).

Since 1990, there has been a substantial focus on changes in the timing of migration of long-distance migrants between Eurasia and Africa; for example, Root et al. (2003), Parmesan (2006), Gordo (2007), Thorup et al. (2007), Vickery et al. (2014) and Jørgensen et al. (2015) discussed these changes from the European perspective. Analysis of long-term population growth rates of European birds carried out by Jørgensen et al. (2015) attributed the population changes to climate change and land-use change, and they found declines in long-distance migrants and farmland habitat specialists. Gregory et al. (2007) used data from the European ornithology network to explore population trends of widespread and common woodland birds for the period 1980–2003. From the data analysed it was determined that long-distance migrants have on average the largest declines in abundance, whereas short-distance migrants have been largely stable, or have increased (Gregory et al. 2007). In the United Kingdom, a new migratory bird indicator highlighted dramatic declines for a whole host of species that spend the northern hemisphere winter in central and southern Africa, these include Nightingales *Luscinia megarhynchos*, Tree Pipits *Anthus trivialis* and Spotted Flycatchers *Muscicapa striata* (RSPB 2014).

Altwegg et al. (2012) and Bussière et al. (2015) discussed these changes from the southern African perspective. There has however been no detailed research, on a continental scale, on how ranges have changed over the past quarter century. Current knowledge of shifts in timing of migration of Palearctic migrants is mainly based on data collected at their European breeding grounds; not much is known about the phenology of Palearctic migrants at their nonbreeding grounds in Africa (Bussière et al. 2015).

The bird species which migrate from Eurasia to southern Africa represent the longest distance migrants, the set of species most likely to be impacted by global climate change (Berthold 1991). This chapter considers 10 of these species, and uses data from two bird atlas projects to describe how their ranges have changed over a period of approximately a quarter century. The midpoints of data collection for the two projects were 1987 and 2012. The chapter also provides a provisional estimate of the change in relative abundance of these species over this period.

The Palearctic migrants that spend the southern summer in South Africa show changes in their distribution and abundance since SABAP1. To understand these changes, we need to look at what has happened on the South African landscape, but we also need to look at what has happened to their European breeding grounds.

Birds are good indicators of environmental changes due to vegetation succession, climate change, land-use change and land management practices (Noble 2016). Population numbers and geographical distributions of birds in Europe are changing rapidly (Florenzano et al. 2016). There has been a general decrease of "farmland" birds and an increase in woodland birds (Florenzano et al. 2016). In many areas of Europe, particularly in former Soviet Union countries, farmland abandonment has led to bush thickening and plant succession (Tryjanowski et al. 2011). Biodiversity in Europe is under threat from agricultural intensification, therefore these areas where shrub and tree encroachment is happening might act as a buffer zone. In parts of eastern Europe, biodiversity in many farmland areas remains healthy, and these are areas that fall outside the Natura 2000 network (Tryjanowski et al. 2011). A good example of a farming management practice that is benefitting biodiversity is the traditional farming model, found throughout Poland and some other eastern European countries, of field division by perennial field margins (Tryjanowski et al. 2011). It creates a heterogeneous landscape which benefits greater species diversity.

During the Northern Hemisphere winter, South Africa is home to many species of migrant birds. For these long-distance migrants, an investigation of changes in distribution and abundance since the First Southern African Bird Atlas Project (SABAP1) are of particular interest. In this chapter, I will consider a selection of 10 Palearctic migrant species: European Bee-eater *Merops apiaster*, Spotted Flycatcher *Muscicapa striata*, European Roller *Coracias garrulous*, Red-backed Shrike *Lanius collurio*, Lesser Grey Shrike *Lanius minor,* Marsh Warbler

Acrocephalus palustris, Willow Warbler *Phylloscopus trochilus*, White Stork *Ciconia ciconia*, Barn Swallow *Hirundo rustica* and Steppe Buzzard *Buteo vulpinus*. With the exception of the Marsh Warbler, these species are the terrestrial species of Palearctic migrants with the largest ranges in southern Africa (Harrison et al. 1997a, b, Underhill and Brooks 2014). The Marsh Warbler was selected because its entire non-breeding range is in the southern third of Africa, and it is known to have increased in abundance rapidly between the two atlas projects (Herremans 1997a, Underhill and Brooks 2014).

Methods

The study area was taken as South Africa, Lesotho and Swaziland, the original area for the Second Southern African Bird Atlas Project (SABAP2) (Underhill 2016). This project commenced in July 2007 and is ongoing. A full description of the SABAP2 protocol was provided by Underhill (2016). In brief, citizen scientists aim to make comprehensive checklists of the presence of bird species in spatial units called pentads, 5 minutes of latitude by 5 minutes of longitude (approximately 9 km by 8 km). The data and maps used in this analysis were downloaded in January 2017.

The formal data collection period for the First Southern African Bird Atlas (SABAP1) was the five-year period 1987–1991, but protocol-compatible data back to 1980 were included in the database (Harrison and Underhill 1997). For SABAP1, data were collected on 15 minutes of latitude by 15 minutes of longitude grid (27 km × 25 km) for SABAP1, instead of the five-minute grid used by SABAP2. There are thus nine SABAP2 pentads in each SABAP1 grid cell, which were known as quarter degree grid cells. For both projects, bird distribution records were collected throughout the year using similar, but not identical protocols. The total number of records of bird distribution assembled by both bird atlas projects amounts to more than 16 million.

The limitations of the overall study area are constrained by the three countries of SABAP2 (South Africa, Swaziland and Lesotho), whereas SABAP1 covered six countries (South Africa, Swaziland, Lesotho, Botswana, Zimbabwe and parts of Mozambique). The spatial scale is determined by SABAP1, which had the coarser grid of the two projects. The SABAP2 pentad-scale data was assembled into SABAP1 quarter degree grid cells. This strategy has been used in all previous comparisons of SABAP1 and SABAP2 data; for example, Altwegg et al. (2012), Broms et al. (2014), Bussière et al. (2015) and Péron and Altwegg (2015a, 2015b).

The key data analysis used in this chapter is also an exploratory data analysis, as described in Chapter 2; it is the range-change map, developed by Underhill and Brooks (2016b). The algorithm is as follows: for each quarter degree grid cell, we have the total number of full protocol checklists submitted for SABAP1 and SABAP2. We limited this analysis to those grid cells for which there were at least four full protocol checklists submitted for both SABAP1 and SABAP2. This choice is the same as made by Underhill and Brooks (2016b), and was based on extensive experimentation with obtaining the balance between showing results for as many grid cells as possible, and reducing the "noise" attributable to sampling variation.

I calculated reporting rates for each species for each grid cell for SABAP1 and 2. The reporting rate is the proportion of checklists which have the species recorded. I used the "Griffioen transformation" to convert reporting rate into an estimate proportional to species density, and used ratios of these estimates as an index of change in relative abundance of the species between SABAP1 and SABAP2 (Griffioen 2001, Underhill 2016, Underhill and Brooks 2016b). For each grid cell in which the species was recorded in either SABAP1 or SABAP2, I calculated the ratio of these values to estimate change in relative abundance for each species that had occurred between projects. The assumption in calculating this ratio is that the detection probability of the species is the same for a single grid cell during both SABAP1 and SABAP2 (but the detection probability can vary between grid cells) (Underhill and Brooks 2016b).

These ratio estimates, especially where based on small sample sizes, show large sampling variation, therefore, it is essential to focus on regional patterns across the landscape rather than on individual grid cells. However, the restriction of the analysis to grid cells with at least four checklists in both projects removes the worst of the sampling variation (Underhill and Brooks 2016b). For each species, I calculated the median of its ratios across all grid cells under consideration. I used the median, rather than the mean, because it is a robust measure of the location of the data, and unlikely to be influenced by the sampling variation described above. If this median is greater than one, it indicates an increase in population size, and if it is less than one, a decrease. This simple measure represents the best currently available index of change in relative abundance between SABAP1 and SABAP2 (Underhill & Brooks 2016b). Currently, this measure exists only in the realm of exploratory data analysis; there is as yet no mechanism in place to construct confidence intervals on this median, or to undertake formal statistical hypothesis testing. Given that the data do not form a random sample from a population of grid cells, but are closer in nature to a census, the statistical analysis approach is not clear.

I also tabulated the median reporting rates for SABAP1 and SABAP2, as well as the median numbers of checklists for both projects; these calculations were once again restricted to the grid cells with at least four full protocol checklists for both projects, and where the species was recorded in either SABAP1 or SABAP2. These quantities provide insight into the reliability of this exploratory data analysis.

Detailed data for each of the 10 species is provided in Appendix 4.A. In this appendix, there are three maps for each species, a summary of the analytical results, and a short text providing contextual background for the species. The first map is a range-change map (Underhill and Brooks 2016b), in which the key results are summarized into six colours: blue means a large increase in abundance; dark green means a moderate increase; light green, small increases; yellow, small decreases; orange, moderate decreases; red, large decreases (Underhill and Brooks 2016b). Under various assumptions described by Underhill and Brooks (2016b), quantitative values are attached to these colours. Grid cells are red if the SABAP2 abundance is estimated to be less than one-third of the SABAP1 abundance, orange if the SABAP2 abundance is between one-third and two-thirds of the SABAP1 abundance, and yellow if the abundance is between unchanged and a decrease of one-third. Light green indicates an increase of up to 1.5 times of the SABAP1 abundance; dark green represents an increase of between 1.5-fold and three-fold, and blue represents a more than three-fold increase in abundance between SABAP1 and SABAP2. In broad brush terms, red, orange and yellow represent grid cells with relative decreases in abundance, and blue, dark green and light green represent grid cells with increases.

For each species, the numbers of grid cells in each colour class in the range-change maps are tabulated in the appendix. The classification into colour classes is based on the relative change in abundance. In particular, large increases in abundance might be off a low baseline (Underhill and Brooks 2016b). The tabulation is therefore performed in two categories, for grid cells for which the SABAP1 reporting was below the median for this project, and those for which it was above the median. Grid cells with SABAP1 reporting rates above the median for that project (bearing in mind that this reporting rate was based on at least four checklists) are likely to have been part of the core of the distribution of the species at the time of the project. It is of particular interest and importance to summarize the relative changes in abundance in these grid cells.

As supplementary information, I have also produced two more range maps for each of the study species, one shows the SABAP1 distribution and the second the SABAP2 distribution. These maps show where the core of a species range was during SABAP1 and where the core is during SABAP2. A comparison of the maps enables a visual analysis of whether the core range of a species has shifted. The detailed interpretation of the SABAP2 pentad-scale map is provided by Underhill and Brooks (2016a). Pentads with four or more checklists are either shaded white, species not recorded, or in colour, with shades based on reporting rate. The cut points between the colours for reporting rates are chosen for each species so that the number of grid cells in each colour are as close to equal as integer arithmetic allows. One sixth of the pentads in which the species occurs are in each colour: the colours are yellow (where the species has the lowest one-sixth of reporting rates, and is at the periphery of its distribution), orange, light green, dark green, light blue and dark blue (where the species has the largest one-sixth of reporting rates, and is in the central core of its distribution. In pentads shaded grey or with white dots, there are one, two or three full protocol checklists, or there are ad hoc lists, or incidental records. In pentads shaded grey, the species was recorded as present; in pentads with white dots the species has not been recorded. If a pentad has four or more checklists, and the species has been recorded on an ad hoc checklist or recorded as an incidental, it is shaded yellow, indicating that the species has a small reporting rate. The distribution maps for SABAP1 are shown at the quarter degree grid cell scale, and all cells in which the species occurred are in colour. To facilitate comparisons, the cut points for the colours are the same as the cut points used for the SABAP2 maps.

Results

For the 10 study species, the median number of checklists for the grid cells under consideration for that species exceeded 28 for all species and both projects (Table 4.1). This smallest number was for the grid cells used in this analysis for the European Bee-eater during SABAP1. The largest median, 100 checklists, was for Marsh Warbler during SABAP2. In other words, in grid cells in which Marsh Warbler had been recorded in either SABAP1 or SABAP2, and which had a minimum of four checklists, there was a median of 100 checklists per grid cell during SABAP2 (and 83 checklists during SABAP1) (Table 4.1). Given these relatively large sample sizes, the impact of sampling variation on the results presented here is likely to be small.

For seven of the 10 species, the direction of the change in relative abundance is an increase (the median in the final column of Table 4.1 is greater than one), and for three species, European Roller, Steppe Buzzard and White Stork, the direction of the change is a decrease. The largest increase was for the Marsh Warbler, for which the analysis suggests an 11-fold increase, and the largest decrease was for the White Stork, for which the analysis suggests that the population in the study area during SABAP2 was 21% of the population during SABAP1. In each case the direction of the change was the same as that suggested by the median reporting rates in SABAP1 and SABAP2 (Table 4.1).

The maps and tables of Appendix 4.A repay close study. The texts in this appendix also highlight key features for each of the 10 species.

Table 4.1 Changes in abundance between SABAP1 and SABAP2 for 10 species of Palearctic migrant in South Africa, Lesotho and Swaziland. The values in each column are medians, computed over quarter degree grid cells with at least four full protocol checklists for both SABAP1 and SABAP2 and in which the species was recorded in either SABAP1 or SABAP2 (see text). The column headed change in abundance is the median of the estimates of change in abundance for these grid cells (see text).

Medians	SABAP1 reporting rate	SABAP2 reporting rate	SABAP1 check-lists	SABAP2 check-lists	Estimated change in relative abundance
European Bee-eater *Merops apiaster*	14.3	16.7	28	30	1.21
Spotted Flycatcher *Muscicapa striata*	5.2	6.6	43	42	1.31
European Roller *Coracias garrulous*	2.9	1.4	60	56	0.52
Red-backed Shrike *Lanius collurio*	6.6	8.3	37	37	1.21
Lesser Grey Shrike *Lanius minor*	6.2	5.9	32	38	1.17
Marsh Warbler *Acrocephalus palustris*	0.2	2.0	83	100	11.27
Willow Warbler *Phylloscopus trochilus*	5.3	6.1	48	45	1.09
White Stork *Ciconia ciconia*	8.3	1.6	48	43	0.21
Barn Swallow *Hirundo rustica*	31.2	34.7	29	29	1.15
Steppe Buzzard *Buteo vulpinus*	15.4	11.4	40	38	0.77

Discussion

Comparison with Vickery et al. (2014)

Vickery et al. (2014) synthesized and reviewed the state of knowledge for the African-Eurasian bird migration system. They considered that the majority of long distance migrants between Europe and Africa were showing decreases in population sizes. They presented long-term trends, expressed as mean percentage annual changes over 30 years. To make the results of this study comparable with the European study, the changes in relative abundance from Table 4.1 were transformed into percentage annual changes, by considering that the middle years of SABAP1 and SABAP2 (1989 and 2011 respectively) were 22 years apart at the time this analysis was undertaken (Table 4.2). Comparisons are available for six of the 10 species considered here. The directions of the changes match for only one species, the Marsh Warbler. For White Stork, the direction of change is negative in southern Africa (6.85% decrease per year) but positive in Europe (3.31%), dramatically different directions. For the remaining four species, there were increases in southern Africa but decreases in Europe (Table 4.2).

The extent of the mismatch between Vickery et al. (2014) and the results of this study is alarming and needs consideration. The most likely explanation is that, for most of the species considered in this study, the breeding areas for the part of the population monitored by Vickery et al. (2014) are largely disjoint from the breeding areas of the part of the population that migrates to southern Africa. Although Vickery et al. (2014) described their results as applicable "throughout Europe", they had data from 25 countries which are all almost exclusively west of 25°E (listed in table 1 of Vickery et al. 2014). In reality, Europe stretches to the Ural Mountains at c. 60°E. In particular, Vickery et al. (2014) had no data for Russia; the European part of this country constitutes about 38% of Europe. Ring recoveries show that the overwhelming majority of Palearctic migrants to southern Africa are breeding east of 25°E in Eurasia (Safring unpubl. data). Thus, the trends discussed by Vickery et al. (2014) need to be treated as trends for Europe west of 25°E, whereas the patterns obtained in this paper are largely representative of the breeding grounds of species which migrate to southern Africa from eastern Europe and Asia. Thus, it is environmental change in these breeding grounds that is impacting the populations migrating to southern Africa.

Potential explanations of observed changes

Of the 10 species considered in this chapter, only the White Stork shows strong avoidance of bush encroached areas (Chapter 3) (Figure 4.1). The Barn Swallow, (Chapter 3) is indifferent to the extent of woody cover, and all the remaining species show a preference for various levels of woody cover, with the Marsh Warbler showing preference for fairly thick woody cover (Chapter 3).

Table 4.2. Annual changes in relative abundance between SABAP1 and SABAP2, with midpoints 22 years apart, transformed from the overall change from Table 4.1, with analogous values, where available, for Europe, from Vickery et al. (2014).

Medians	Overall change in relative abundance	Annual change: southern Africa (% per year)	Annual change: Europe (% per year)
European Bee-eater *Merops apiaster*	1.21	+0.87	–
Spotted Flycatcher *Muscicapa striata*	1.31	+1.23	–1.92
European Roller *Coracias garrulus*	0.52	–2.93	–
Red-backed Shrike *Lanius collurio*	1.21	+0.87	–1.53
Lesser Grey Shrike *Lanius minor*	1.17	+0.72	–
Marsh Warbler *Acrocephalus palustris*	11.27	+11.64	+0.48
Willow Warbler *Phylloscopus trochilus*	1.09	+0.39	–1.37
White Stork *Ciconia ciconia*	0.21	–6.85	+3.31
Barn Swallow *Hirundo rustica*	1.15	+0.64	–0.68
Steppe Buzzard *Buteo vulpinus*	0.77	–1.18	–

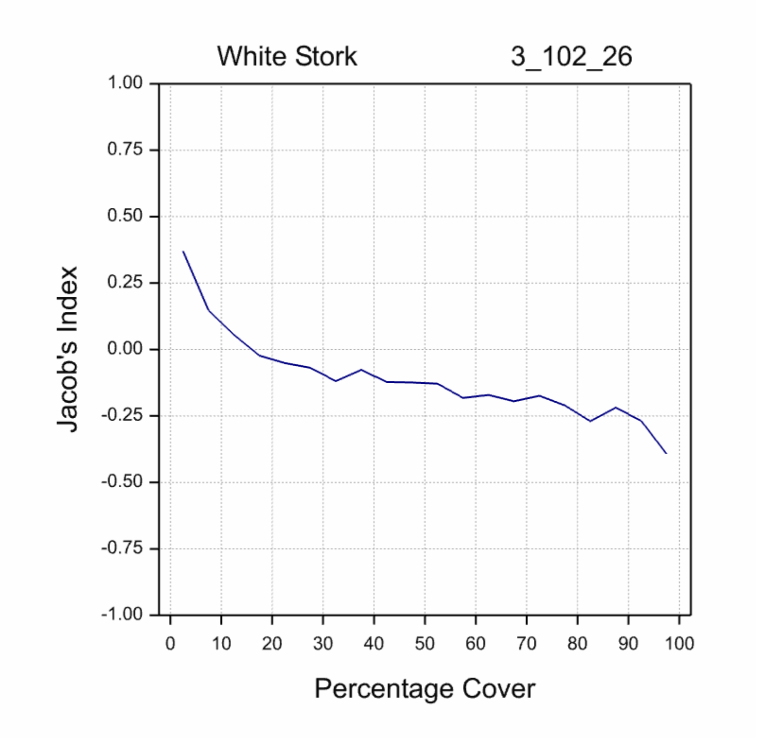

Figure 4.1 Woody cover preference plot for White Stork (see Chapter 3).

It is an important exercise to consider what the likely pattern of distributional change would be for a Palearctic migrant which arrives in southern Africa in unchanged numbers, but experiences additional habitat available to it due to bush encroachment between SABAP1 and SABAP2. They would spread themselves out across the larger amount of suitable habitat. The likely change in distribution would be to have smaller numbers of birds per grid cell in SABAP2 than in SABAP1, because they would be spread over a larger number of grid cells, and the average reporting rate would thus decrease. The algorithm used in this chapter would then estimate an overall decrease in population size, because the algorithm calculates the median of the changes across the grid cells in which the species was recorded. The reality is that the conservative approach adopted here shows increases in abundance for seven of the 10 species (Table 4.2); these seven species all benefit to a greater or lesser extent from bush encroachment.

The observed increases in abundance between SABAP1 and SABAP2 must therefore indicate increased numbers of birds of these species arriving in southern Africa, and the most likely location of these increases must be on the breeding grounds. Thus, the focus of this section of this chapter is on habitat changes on the likely breeding grounds of the part of the population which migrate to southern Africa. The exact details of the limits of these breeding grounds are largely unknown but are likely to be mostly east of the section of Europe considered by Vickery et al. (2014). There does not appear to be a review of habitat change in eastern Europe, and thus this discussion is largely dependent on fragmentary evidence.

There are reports of increases in abundance of shrub-dwelling species, due to bush encroachment, in southern Europe (which includes the countries Spain, Portugal, the Italian peninsula, southern France, Greece and Malta) (Reif and Hanzelka 2016). Bush encroachment is also one of the main causes of grassland habitat loss in central Europe (Elias and Tischew 2016). Central Europe includes the countries Austria, Croatia (sometimes placed in southeastern Europe), Czech Republic, Germany, Hungary, Liechtenstein, Poland, Slovakia, Slovenia (sometimes placed in southeastern Europe), and Switzerland (Ash 1999). Elias and Tischew (2016) found that abandoned semi-natural grasslands and farmland in central Europe are often overgrown with thorny, woody shrubs and that bush encroachment is one of the main causes of grassland loss in central Europe. In the Moscow Region and Novgorod of western Russia, many farms on the floodplain meadows were abandoned during the 1980s and 1990s as the former Soviet Union was coming to an end (Mischenko and Sukhanova 2016). This led to these areas becoming overgrown with shrubs and small trees (Mischenko and Sukhanova 2016). Bird species that would have increased in abundance, are those that have benefitted from an increase of dense and tall vegetation, such as Marsh Warblers *Acrocephalus palustris* and Booted Warblers *Hippolais caligata* (Mischenko and Sukhanova 2016). Species which have shown a decline in abundance are those that prefer short grass habitats, such as Terek Sandpiper *Xenus cinereus* (Mischenko and Sukhanova 2016).

Land abandonment, which occurred at a large scale after the fall of the Soviet Union in the 1990s, has led to temporary increases in biodiversity of bird populations because these fallow lands undergo plant succession, where shrubs and trees start appearing in areas that were once open fields. This heterogeneity in habitats tends to attract a whole host of species (Tryjanowski et al. 2011). Land abandonment has led to increased habitat heterogeneity as open fields steadily transition to areas with more structural diversity due to trees and shrubs (Herzon et al. 2006). Habitat heterogeneity has a positive effect on biodiversity (Herzon et al. 2006). In Slovakia, land abandonment had a positive effect on the Lesser Grey Shrike *Lanius minor* (Krištín et al. 2000). Lesser Grey Shrikes benefited from the increased shrub cover and habitat structural diversity in a mostly agricultural landscape that dominated breeding territories of this species (Krištín et al. 2000). In these areas, there was a high availability of insects and other invertebrates, which are the main food source of the Lesser Grey Shrike (Tryjanowski et al. 2011). In southwestern Slovenia, open landscapes of the Karst Plateau are disappearing because of forest succession (Kmecl 2016). Kmecl (2016) found a strong positive link between early forest succession and bird diversity, in other words, habitats where there are some trees and bushes, but still a good number of open patches too. Kmecl (2016) recommended that forest management policy should manage for larger open landscapes in between forest areas to maintain habitat diversity and therefore bird and other species diversity.

Jähnig et al. (2016) found that climate change and a decline in pastoral farming practices have caused a loss of open habitats resulting from an upwards shift in the treeline in the Alps. Grassland birds are losing out, but the highest bird species diversity was found at a shrub cover of about 60% (Jähnig et al. 2016). Maintaining a shrub cover of roughly 60% could be set as a land management goal to preserve species richness and diversity in this area (Jähnig et al. 2016).

The most parsimonious explanation for the majority of range changes is bush encroachment, which has occurred for a variety of reasons, across much of the northern and eastern half of South Africa (O'Connor et al. 2014), as well as parts of mainly eastern Europe. It seems that the bird species that have benefitted from bush encroachment are mainly small insectivores and frugivores, and include most of the Palearctic migrants which spend the southern summer in the study area of South Africa, Lesotho and Swaziland. The emerging hypothesis is that habitat change, mainly bush encroachment, in eastern Europe following the collapse of the farming practices of the former Soviet Union, has resulted in increased breeding productivity for these species. The increased populations arriving in southern Africa have been accommodated because the habitat available to them has increased in southern Africa as well due to bush encroachment. In other words, fortuitously, the hypothesis is that there has been an expansion in suitable habitat in both the breeding and non-breeding areas for these species.

The three most widespread terrestrial migrant species which have decreased in range (and abundance) between SABAP1 and SABAP2 are White Stork, European Roller and Steppe Buzzard; of the 10 species they are the largest in size. For all three species it is feasible that the loss of agricultural landscapes after the collapse of the collective farming systems of the Soviet Union has negatively impacted their productivity on the breeding range. They are all described as benefiting from agricultural landscapes, especially fragmented mosaic systems, with a mixture of meadows and pastures with some trees. These habitats are now likely to be more scarce than they were before the end of the Soviet Union. For these species, the decreases observed in South Africa seem more likely to be due to changing conditions in the north than in the south.

Gaps in knowledge and information needs

This chapter has highlighted a series of information needs which are critical for an understanding of bird populations migrating to mainly eastern and southern Africa from the eastern half of Eurasia.

1. In general, there is a lack of bird monitoring data for eastern Europe, and especially for Russia. An eastwards expansion of the detailed bird monitoring programmes achieved in western Europe is needed if we are to fully understand the drivers behind changes in abundance for the species which breed there.

2. There is a critical need for a review of habitat changes in eastern Europe following the collapse of the Soviet Union. The information presented above is an assembly of the available information in the literature, and is fragmentary.

3. In Africa, there is a huge lack of detailed atlas data north of southern Africa. The greatest need in conservation ornithology in Europe is an African Bird Atlas. We have remarkably little information on detailed distributions of migrant bird species in Africa during the non-breeding season, and how this is changing in the face of development and climate change, and we therefore cannot conserve these species properly. Currently, there are bird atlas projects underway in Nigeria and Kenya which follow the same data collection protocol as SABAP2 (Tende et al. 2016, Kung'u and Jackson 2017). This initiative needs to extend to cover all, or as much as possible, of Africa. This will ensure that we get a clearer picture of bird population trends.

4. Even within South Africa, there is a lack of good comprehensive data on bush encroachment. This need has recently been partially met by Skowno et al. (2016) who developed a map on woody cover expansion based on Landsat imagery for the period 1990 to 2013. Unfortunately, LiDAR technology is relatively new, so it will be take another 5–10 years before reliable maps showing changes in woody cover become available from that source, but these are being developed with the Remote Sensing Group at the CSIR, Pretoria (M. Cho pers. comm.). LiDAR maps of woody cover for the entire African continent are a priority; this thesis shows that these data are of great value in understanding bird distributions in savanna habitats.

Conclusion

Seven of the 10 most widespread long-distance terrestrial migrants in South Africa displayed increases in abundance in the quarter-century between the first and second bird atlas projects. This result is at variance with the finding of

Vickery et al. (2014) who considered that most long-distance Eurasian migrants to Africa were showing serious decreases. Although Vickery et al. (2014) considered their results to be Pan-European, they actually only had trend data from the western half of Europe. The most important conclusion from this chapter is a realization of the need to extend the bird monitoring studies of western Europe eastwards to Russia, including east of the Ural Mountains, into Asia. This chapter suggests that bird trends over much of the former Soviet Union differ from those of western Europe.

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APPENDIX 4.A Detailed results for each of the 10 Palearctic migrants considered in this chapter.

This appendix provides the detailed results for each of the 10 Palearctic migrants considered in this chapter. This is done in the section headed Analysis for each species. A section headed Background provides the key relevant details about the biology of the species.

European Bee-eater

Analysis

The core distribution of the European Bee-eater during SABAP1 was in north-eastern and north-western parts of South Africa (Figure 4A.1). Between SABAP1 and SABAP2, its core range has shifted to the south and east when the two distribution maps are compared (Figure 4A.1).

Table 4A.1 Summary of changes in the relative abundance of the European Bee-eater between SABAP1 and SABAP2 (Figure 4A.1, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	122	137	259	21.3
ORANGE	25	125	150	12.3
YELLOW	21	110	131	10.8
LIGHT GREEN	30	110	140	11.5
DARK GREEN	86	111	197	16.2
BLUE	308	32	340	27.9
Total	592	625	1217	100

The analysis for the European Bee-eater was based on 1217 grid cells, for which at least four full protocol checklists have been submitted for both SABAP1 and 2, and the species recorded in these grid cells in either SABAP1 or 2. This species has shown large increases in abundance (shaded blue) in 340 (27.9%) grid cells and moderate increases (shaded dark green) in 197 (16.2%) grid cells (Table 4A.1). It has shown very large decreases (shaded red) in abundance in 259 (21.3%) grid cells and large decreases (shaded orange) in 150 (12.3%) grid cells. European Bee-eaters have shown moderate or large increases in abundance in

44.1 % of its South African range (dark green and blue grid cells) and moderate or large decreases in 33.6 % of the grid cells (red and orange grid cells). The median change in their abundance is 1.21 (i.e. they have increased by 21% since SABAP1) (Table 4.1). Most of the increases occurred in northern and eastern South Africa, in the Savanna Biome and the decreases occurred in the west of the Eastern Cape Province (Figure 4A.1).

Of the 340 grid cells for which the European Bee-eater showed large increases, in theory three-fold increases, only 32 had had reporting rates above the median for SABAP1; in contrast, of the 259 grid cells which showed large decreases in abundance, 137 of these were grid cells which had formed part of the core range of the species in SABAP1 (Table 4A.1) (Figure 4A.1).

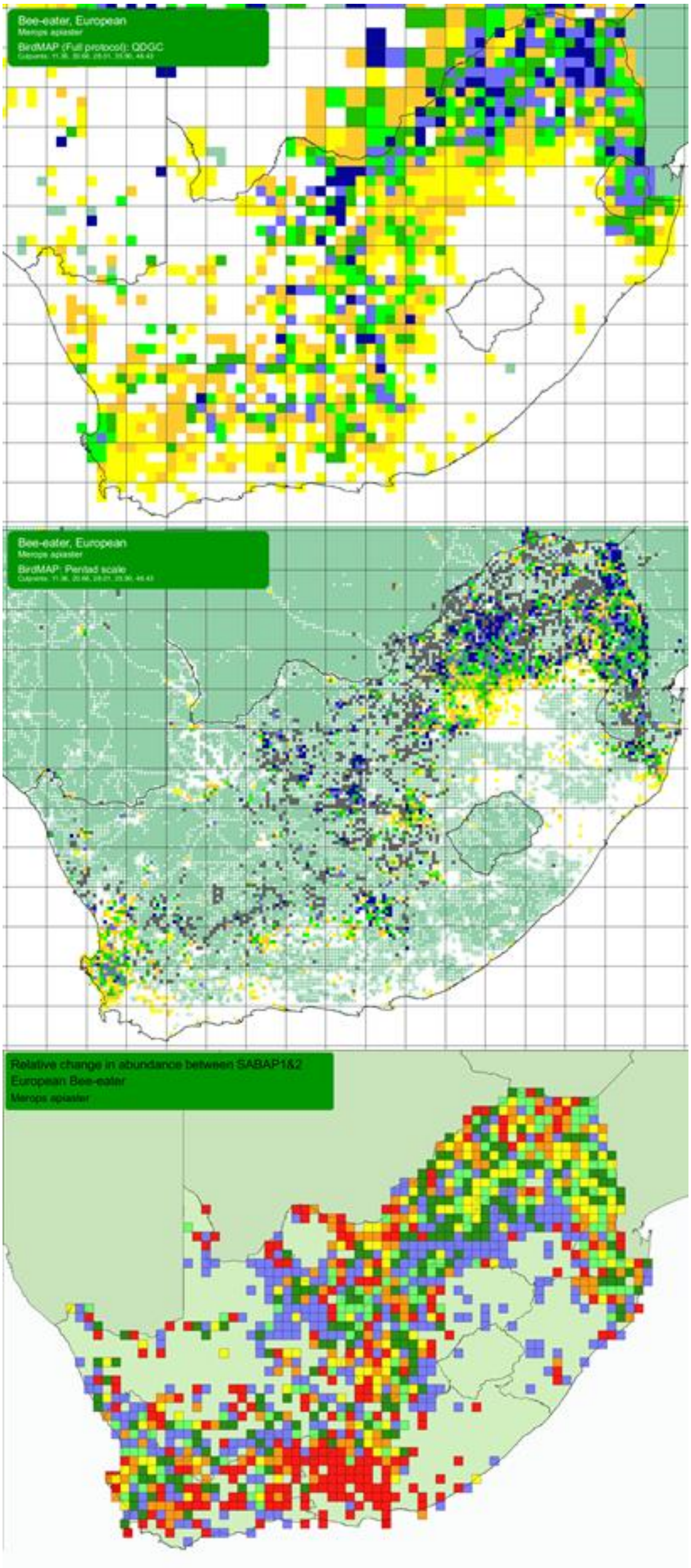

Figure 4A.1 Maps for the European Bee-eater. Top: SABAP1 distribution. Middle: SABAP2 distribution. Bottom: Range-change map. See text for further details of interpretation.

Background

There are two sub-populations in southern Africa. One population breeds in various areas of Eurasia and northern Africa, migrating to south-central and southern Africa in about October for the non-breeding season, leaving again in about March (Hockey et al. 2005). This non-breeding season population occurs in Namibia, Mozambique, Zimbabwe, Botswana and the north-eastern parts of southern Africa. The southern African breeding population arrives from their non-breeding grounds in central Africa in September. They mainly breed in the Western and Eastern Cape Provinces of South Africa, leaving southern Africa in the period from January-February (Underhill 1997). Most of the grid cells displaying decreases lie within the range of the breeding population in the southwestern parts of South Africa, especially the Eastern Cape Province (Figure 4A.1).

The most recently published national atlas for a European country is for Germany (Gedeon et al. 2014). In Germany, as in other parts of central Europe, the breeding range of the European Bee-eater is expanding northwards, possibly attributable to climate change. The same range expansion process is probably taking place all along the northern edge of the breeding range and driving the observed increase in population in southern Africa.

European Bee-eaters occur in a variety of habitats, especially shrubland and woodland (Underhill 1997). They eat insects, including bees, flying ants, wasps and termites (Hockey et al. 2005). They often make use of perches from which they dive to catch insects in flight or on the ground (Hockey et al. 2005). The expansion in their core range could be attributed to bush encroachment due to the higher availability of shrubs and trees which they use as perches.

Spotted Flycatcher

The core of the Spotted Flycatcher's range during SABAP1 was concentrated towards the north-west of South Africa into Botswana (Figure 4A.2). The core range has shifted substantially eastward and southward from where it was during SABAP1 (Figure 4A.2).

Table 4A.2 Summary of changes in the relative abundance of the Spotted Flycatcher eater between SABAP1 and SABAP2 (Figure 4A.2, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	123	176	299	24.7
ORANGE	34	65	99	8.2
YELLOW	26	90	116	9.6
LIGHT GREEN	27	113	140	11.6
DARK GREEN	42	122	164	13.5
BLUE	351	42	393	32.5
Total	603	608	1211	100

The total number of grid cells, with four full protocol checklists or more in both SABAP1 and 2, in which the Spotted Flycatcher has been recorded was 1211. It shows large increases in 393 (32.5%) grid cells and moderate increases in 164 (13.5%) grid cells (Table 4A.2). It shows large decreases in 299 (24.7 %) of the grid cells and moderate decreases in 99 (8.2%). The increases outweigh the decreases. The overall trend is thus an increase in abundance, especially in the Savanna Biome. The estimated median change in their abundance is 1.31 (i.e. they have increased by 31% since SABAP1) (Table 4.1).

Only 42 of 393 grid cells where it was recorded at above median reporting rates in SABAP1 showed large increases. In contrast, 176 of the 299 grid cells where Spotted Flycatcher was at reporting rates above the median in SABAP1 showed large decreases. This suggests that habitat that was suitable has become unsuitable. Taken together, the results suggest not only an increase in abundance, but also shift in distribution.

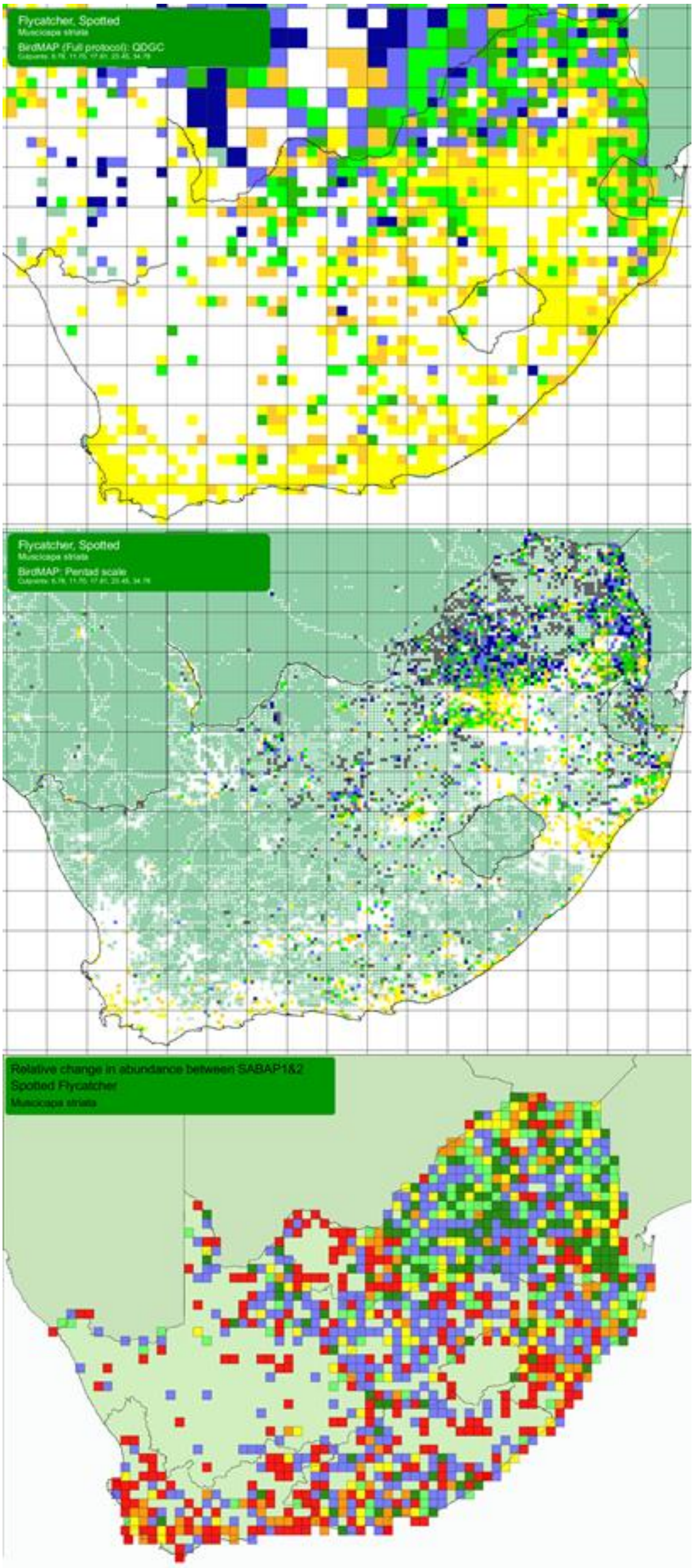

Figure 4A.2 Maps for the Spotted Flycatcher. Top: SABAP1 distribution. Middle: SABAP2 distribution. Bottom: Range-change map. See text for further details of interpretation.

The Spotted Flycatcher likes habitats with good perches from where it can scan for prey (mainly insects) (Hockey et al. 2005). They often hawk for insects from perches, sweeping down to catch insects in flight and then returning to the same perch (Herremans 1997b). Their preferred habitats include open woodland, scrubland, gardens and even areas with stands of alien trees (Hockey et al. 2005). They breed throughout most of Europe in the northern hemisphere summer, migrating to their non-breeding grounds in sub-Saharan Africa during the northern winter. Spotted Flycatchers arrive in southern Africa during the period from mid-October to late November, and return to the northern hemisphere around mid-March to early April (Hockey et al. 2005).

The Spotted Flycatcher's SABAP2 core range map shows an increase in reporting rates in the Kruger National Park compared to SABAP1. During SABAP1 their highest reporting rates in South Africa came from moist woodland, miombo, arid woodland and mopane (Herremans 1997b). The shift of its core range towards the east could indicate a shift in these vegetation types because of bush encroachment, and its former core range in the west having become too thick (woody).

A study by the Royal Society for the Protection of Birds (RSPB) (2014) on Spotted Flycatchers in the United Kingdom (UK) found that nests that were built in gardens produced twice as many chicks as nests in closed woodland and farmland habitats, potentially this means that the woodland and farmland habitats have become less optimal (RSPB 2014). Baillie et al. (2006) determined that Spotted Flycatchers are declining rapidly in the UK. Their UK population decreased by an estimated 82% for the period 1978–2003 (Baillie et al. 2006). The observed increase in southern Africa suggests that the trend in the breeding area of the species in eastern Europe and western Asia is the opposite to the large decreases recorded in western Europe (Table 4.2, Vickery et al. 2014). This is a species that is likely to be benefitting from the collapse of the farming systems of the former Soviet Union.

Bussière et al. (2015) examined shifts in the timing of migration for several species in the Highveld region of South Africa. They found that almost a third of the species included in their study have shifted their arrival date or departure date or both. Spotted Flycatchers and Red-backed Shrikes both have quite northern breeding ranges in Europe (Bussière et al. 2015). Both these Palearctic terrestrial migrants have advanced their migration departure dates (Bussière et al. 2015). These results strengthen the hypothesis that climate change in the northern hemisphere breeding ranges of long-distance migrant birds is driving shifts in their migration phenology.

European Roller

Analysis

The core distribution during SABAP1 was located in the Kruger National Park, a scattering of grid cells in the north-west of South Africa and in north-eastern KwaZulu-Natal Province (Figure 4A.3). The core distribution has retracted almost completely to the Kruger National Park and its surrounding areas (Figure 4A.3).

Table 4A.3 Summary of changes in the relative abundance of the European Roller between SABAP1 and SABAP2 (Figure 4A.3, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	121	191	312	43.8
ORANGE	23	55	78	11.0
YELLOW	15	50	65	9.1
LIGHT GREEN	16	36	52	7.3
DARK GREEN	23	22	45	6.3
BLUE	154	6	160	22.5
Total	352	360	712	100

The European Roller has been recorded in 712 grid cells, showing large decreases in abundance in 312 (43.8%) grid cells and moderate decreases in 78 (10.9%) grid cells. It has displayed large increases in 160 (22.5%) grid cells and moderate increases in 45 (6.3%) grid cells (Table 4A.3). Of the 312 grid cells in which large decreases were recorded, 191 of the 312 grid cells (61%) were grid cells that were in the core of the range during SABAP1. The overall trend is that of decline. It has experience either large or moderate decreases in abundance over 54.8% of its range in South Africa and Swaziland. The median of the 712 estimates of relative change in abundance between SABAP1 and 2 was 0.52 (Table 4.1), suggesting that the population has decreased by almost half. This is clearly a species in trouble.

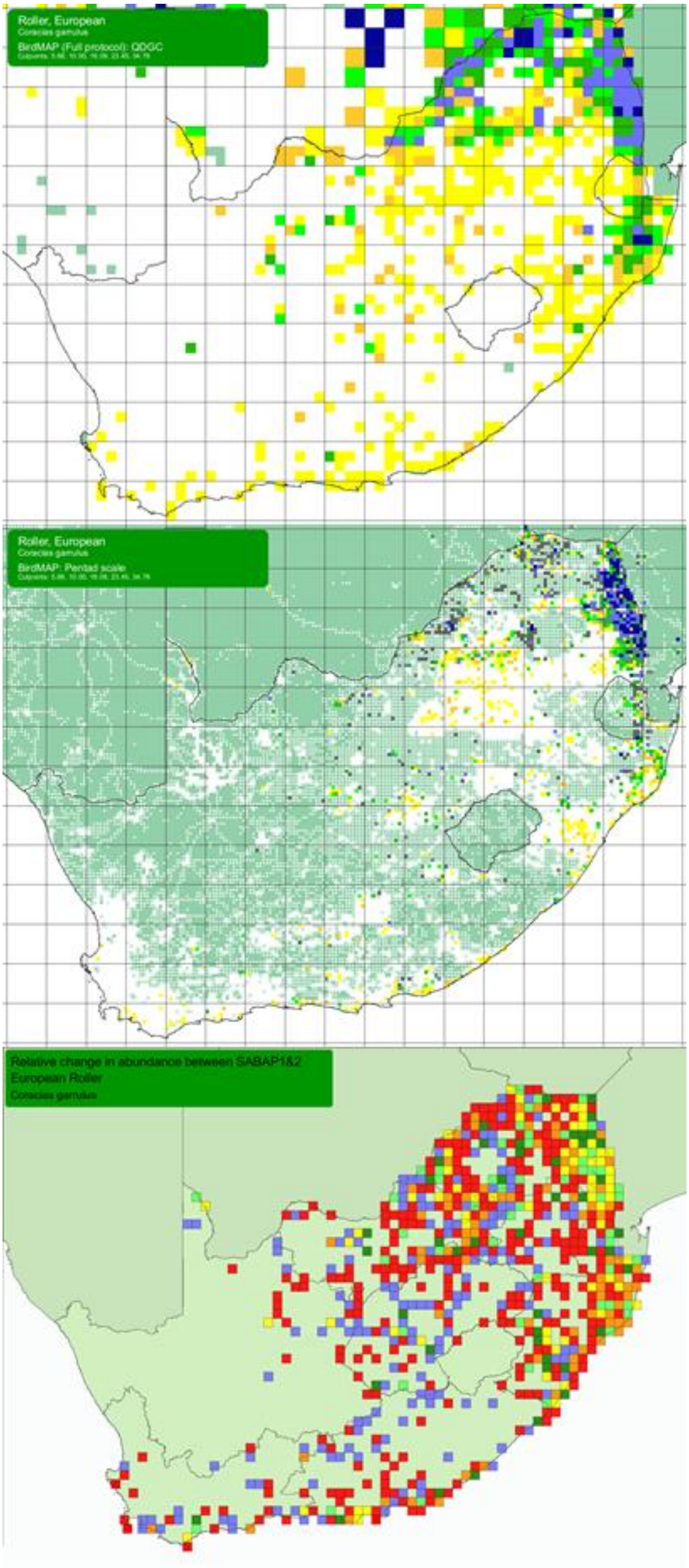

Figure 4A.3 Maps for the European Roller.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

In southern Africa, European Rollers prefer open savanna habitats, especially *Vachellia* and broad-leaved woodlands with grassy clearings. They prefer open woodland areas and are marginal in vegetation types that have a less well developed woody component, like that of the Central Kalahari and the Grassland Biome (Herremans 1997c). Their preference for open woodland suggests that if an area becomes too thick (i.e. the woody cover component becomes dominant), it's likely that they will move out of an area in search of more suitable habitat.

In Europe, they breed in dry, warm, open habitats with scattered trees, thickets and open oak or pine woodlands (Fry et al. 1992, Svensson et al. 2010). Their breeding grounds occur throughout temperate, steppe and the Mediterranean zones of Eurasia (Kovacs et al. 2008). European Rollers eat insects and other small invertebrates (Hockey et al. 2005). They make use of perches (trees, shrubs, dead branches) where they sit and wait and scan for prey, which mostly is caught on the ground (Hockey et al. 2005).

In January 2017, the RSPB and BirdLife Hungary, under the framework of two European Union LIFE Projects, facilitated the European Roller International Conference Workshop in Kecskemét, Hungary. The goal of the workshop was to develop a good foundation and sound strategy for a new International Species Action Plan for the European Roller (CMS 2017). European Rollers are listed on Appendices I and II by the Convention on the Conservation of Migratory Species of Wild Animals (CMS) (CMS 2017). They are showing decreasing populations trends globally, for this reason they are included in the Annexes of the CMS Action Plan for Migratory Landbirds in the African-Eurasian Region (AEMLAP; under Resolution 11.17) (CMS 2017). European Rollers are already extinct in Slovakia and the Czech Republic and a relic population in Latvia now forms the northern limit of their breeding range (BirdLife South Africa 2017). Their population numbers are decreasing over most of their range in north-eastern Europe (BirdLife South Africa 2017). Many western European countries, such as Germany, Switzerland, Denmark, Sweden, Finland and Czech Republic have lost all their breeding pairs (Snow and Perrins 1998).

The main threat faced by European Rollers in Europe is the increase in intensive agriculture, especially for milk production. Other threats include; wind farms, poisoning by pesticides, urbanization, and illegal killing and taking during migration (CMS 2017). The intensification of agricultural has largely been driven by the European Union's Common Agricultural Policy (CAP), the subsidies of which has led to the homogenization of landscapes through the felling of mature trees and the conversion of natural grasslands to croplands or grazing pastures

(CMS 2017). It has also been determined that the decline of European Roller populations is caused by a loss of foraging and nesting sites (tree cavities) (BirdLife Hungary 2013). Nest sites are being impacted by an increase in invasive hardwood tree species which are not likely to form natural tree cavities like the native softwood trees (BirdLife Hungary 2013). European Roller populations in southern Europe, the Mediterranean specifically, seems to be stable (BirdLife South Africa 2017).

Finch et al. (2015) studied migratory connectivity of European Rollers between breeding sites in Europe, all west of 25°E, and their non-breeding sites in Africa. They showed no connectivity between the western half of Europe and my study area in southern Africa. Presumably southern African rollers therefore migrate to eastern Europe and western Asia. The explanation for the –2.93% decrease in population size per year in southern Africa (Table 4.2) probably needs to be found in this part of the breeding range. Given the need for fairly open habitats in the breeding season, the collapse of the agricultural practices of the former Soviet Union has possibly led to breeding area habitats which have become too heavily bush-encroached for this species and have contributed to its decline.

The CMS reports that there are major knowledge gaps for the European Roller's African non-breeding sites (CMS 2017). The data of SABAP1 and SABAP2 can help fill these gaps.

Red-backed Shrike

Analysis

The core of the Red-back Shrike's distribution was concentrated towards the north-west of South Africa and into Botswana (Figure 4A.4). This area forms part of the bushveld or Kalahari sandveld/thornveld. The Red-backed Shrike's core range has shifted south and east compared to SABAP1 and especially into the Free State Province in central South Africa, and adjacent provinces (North West and Eastern Cape) (Figure 4A.4).

Table 4A.4 Summary of changes in the relative abundance of the Red-backed Shrike between SABAP1 and SABAP2 (Figure 4A.4, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	107	142	249	22.9
ORANGE	27	84	111	10.2
YELLOW	24	98	122	11.2
LIGHT GREEN	34	94	128	11.8
DARK GREEN	55	87	142	13.1
BLUE	295	39	334	30.8
Total	542	544	1086	100

The Red-backed Shrike has been recorded in 1086 grid cells which qualified for the analysis. It shows large increases in abundance in 334 (30.8%) grid cells and moderate increases in 142 (13.1%) grid cells (Table 4A.4). It shows large decreases in abundance in 249 (22.9%) grid cells and moderate decreases in 111 (10.2%) grid cells (Table 4A.4). The increase in abundance has either been large or moderate in 43.9% of the 1086 grid cells considered in the analysis. The median increase in abundance is estimated to be 21% (Table 4.1). 295 of the grid cells where very large increases have been recorded (shaded blue, 334 cells) are grid cells where the reporting rate during SABAP1 was below the median for Red-backed Shrikes.

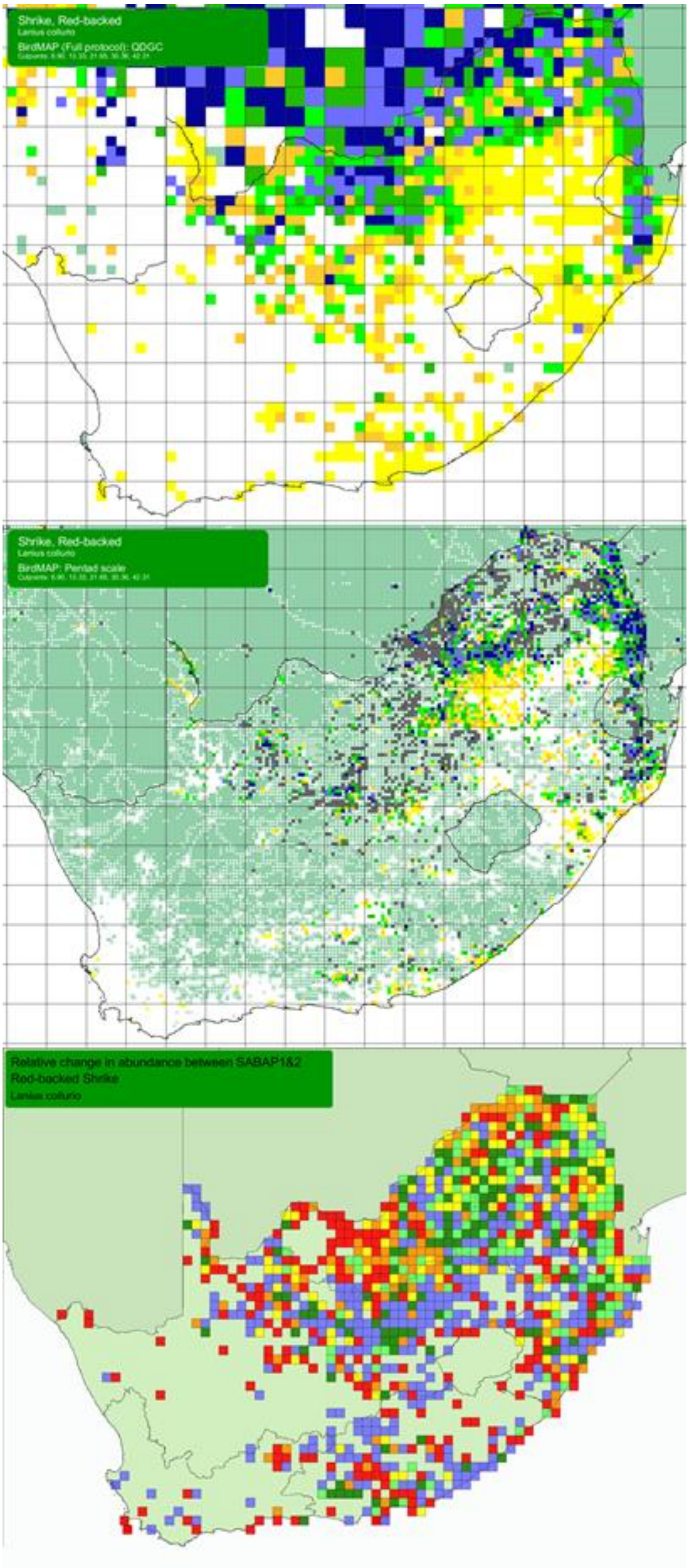

Figure 4A.4 Maps for the Red-backed Shrike.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

Red-Backed Shrikes prefer habitats with a medium density of thornveld/*Vachellia* scrubland and woodland (Herremans 1997d). Females prefer denser woodland habitats and males prefer areas with smaller trees and scattered open patches in between (Herremans 1997d). Red-backed Shrikes mainly eat insects and other arthropods, and sometimes even small birds (Hockey et al. 2005). In a study on grasshoppers, a prey item of the Red-backed Shrike, Barker (1985) noted that overgrazing by livestock might reduce grasshopper populations, but it results in bush encroachment and therefore an expansion of the Red-backed Shrike's preferred habitat.

Lesser Grey Shrike

Analysis

The core of the Lesser Grey Shrike's distribution was concentrated towards the north and the west of South Africa and into Botswana (Figure 4A.5), similar to that of the Red-backed Shrike. This area forms part of the bushveld or Kalahari sandveld/thornveld. The Lesser Grey Shrike's core range has shifted south and east compared to SABAP1 and especially into the Free State Province, Gauteng and KwaZulu-Natal (Figure 4A.5). It also seems like the Lesser Grey Shrike has become slightly more abundant in the Kruger National Park since SABAP1, the lowveld region of South Africa (Figure 4A.5).

Table 4A.5 Summary of changes in the relative abundance of the Lesser Grey Shrike between SABAP1 and SABAP2 (Figure 4A.5, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	76	128	204	26.2
ORANGE	16	75	91	11.7
YELLOW	11	53	64	8.2
LIGHT GREEN	26	40	66	8.5
DARK GREEN	43	62	105	13.5
BLUE	217	31	248	31.9
Total	389	389	778	100

The Lesser Grey Shrike has been recorded in 778 grid cells (with at least four full protocol checklists for both SABAP1 and 2), showing large decreases in abundance in 204 (26.2%) grid cells and moderate decreases in 91 (11.7%) grid cells. It has displayed large increases in 248 (31.9%) grid cells and moderate increases in 105 (13.5%) grid cells (Table 4A.5). The overall trend is that of increase in relative abundance. Of the 248 grid cells in which large increases have been recorded, 31 of the 248 grid cells (12.5%) are above the median reporting rate as compared to SABAP1. It has experienced either large or moderate increases in abundance over 45.4% of its range in South Africa and Swaziland. The median of the 778 estimates of relative change in abundance between SABAP1 and 2 was 1.17 (Table 4.1), suggesting that the population has increased by 17% since SABAP1.

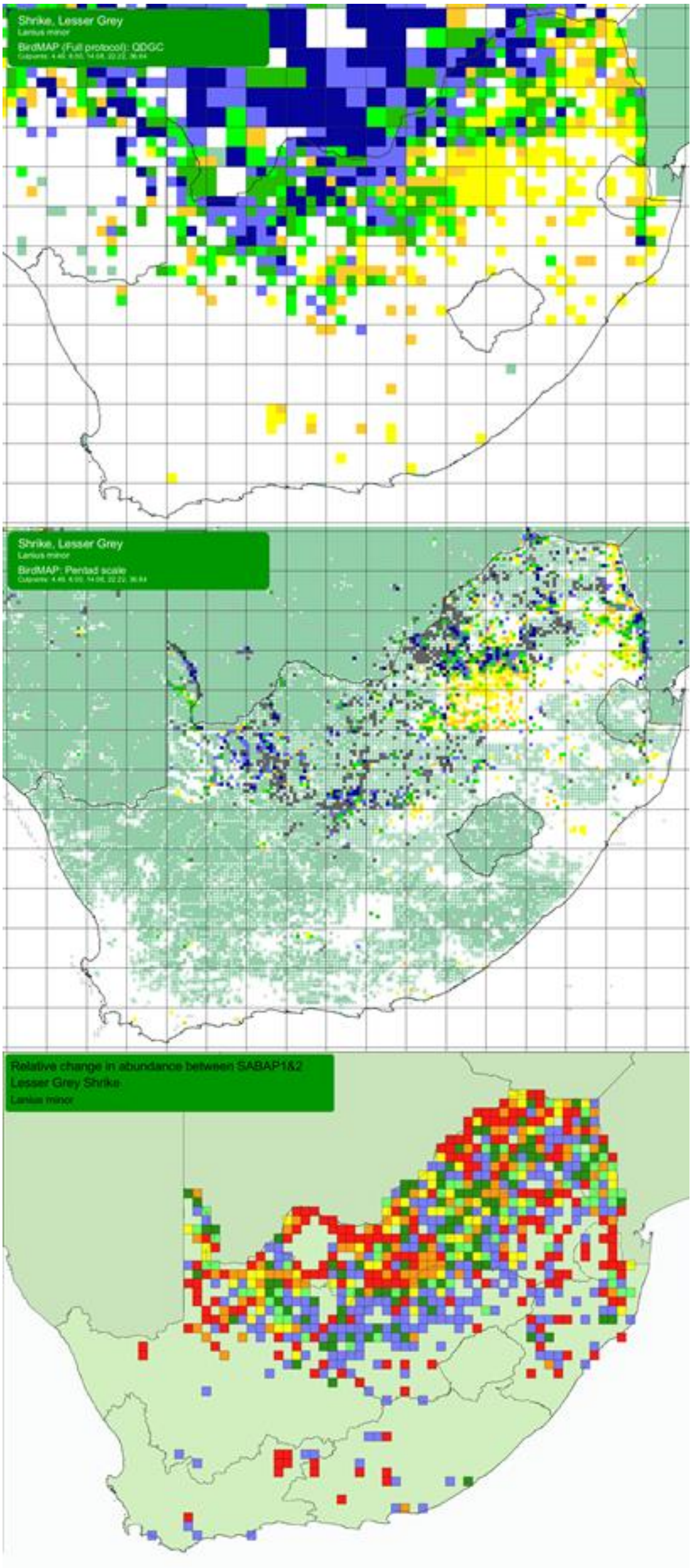

Figure 4A.5 Maps for the Lesser Grey Shrike.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

The Lesser Grey Shrike breeds across Eurasia, from Spain to Siberia and north-west China (Hockey et al. 2005). Almost the entire world population spends its time in southern Africa during the non-breeding season (Herremans 1997e). It prefers habitats with scattered trees and low bushes, especially *Vachellia* savanna and thornveld, but also stunted mopane woodland (like in the north-eastern parts of South Africa) as well as mixed *Terminalia* and *Philenoptera* woodland in the Kalahari (Herremans 1997e). Lesser Grey Shrikes are also often found on fallow land with scattered thorny bushes (Herremans 1997e). This is a species that might be benefitting from bush encroachment.

A European study by Moga et al. (2010) found that Lesser Grey Shrikes, during breeding season, prefer habitats where there are arable fields and herbaceous vegetation, as well as small shrubs and some tree cover.

Analyses of the SABAP 1 and 2 data show an increase in abundance of the Lesser Grey Shrike (Table 4.1). This stands in contrast with the findings of the Pan-European Common Bird Monitoring Scheme, which reports a sharp decline of 60% for the period 1999-2013 (EBCC 2015) (Figure 4A.6), but this data are only for Bulgaria, Greece, Hungary and Italy.

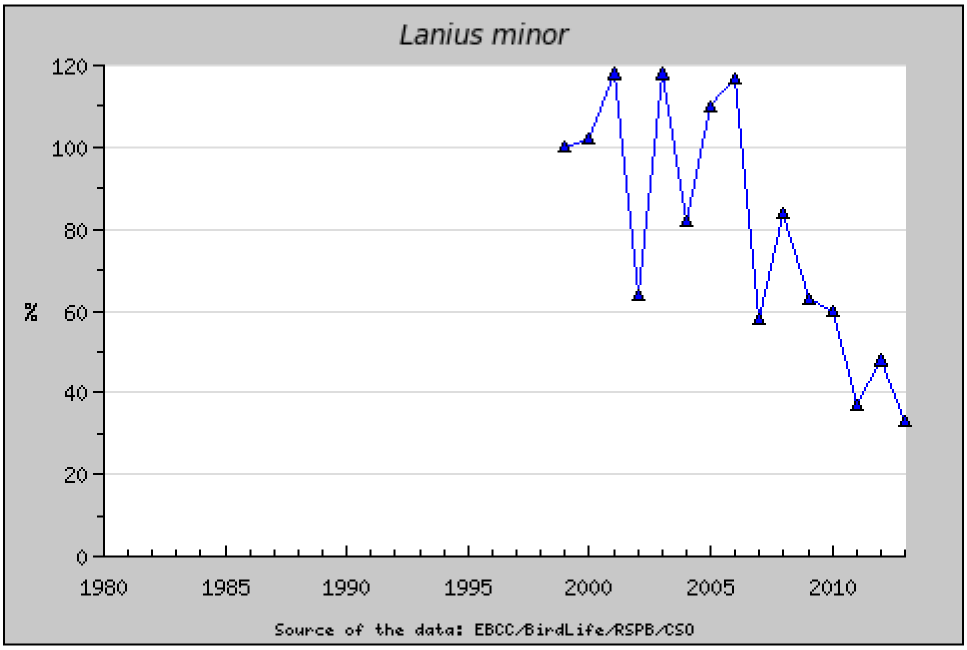

Figure 4A.6 Population index (%) 1999-2013 for Lesser Grey Shrike *Lanius minor* for Europe (Bulgaria, Hungary, Greece, Italy) showing a steep decline (EBCC 2015).

Marsh Warbler

Analysis

During SABAP1 the core of the Marsh Warbler's distribution was concentrated to the coast of the Eastern Cape Province, north of Port St Johns and in eastern Swaziland, with low reporting rates on the central Highveld, in and around Gauteng Province (Figure 4A.7). The core distribution has shifted northwards along the eastern coast of South Africa to the areas surrounding Durban and Pietermaritzburg as well as shifting and expanding its core range to the north of Swaziland (Figure 4A.7). Fieldwork coverage in Swaziland for SABAP2 has not been as intensive as for SABAP1.

Table 4A.6 Summary of changes in the relative abundance of the Marsh Warbler between SABAP1 and SABAP2 (Figure 4A.7, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	0	94	94	22.8
ORANGE	0	16	16	3.9
YELLOW	0	13	13	3.1
LIGHT GREEN	0	22	22	5.3
DARK GREEN	0	26	26	6.3
BLUE	205	37	242	58.6
Total	205	208	413	100

The total number of grid cells, with four full protocol checklists or more for both projects, and in which the Marsh Warbler has been recorded, is 413, the least of the 10 species considered in this chapter. It has large increases in 242 (58.6%) grid cells and moderate increases in 26 (6.3%) grid cells (Table 4A.6). It has very large decreases in 94 (22.8 %) of the grid cells and large decreases in 16 (3.9%) grid cells (Table 4A.6). Overall it has an apparent increase in abundance in 64.9% of its range in South Africa, Lesotho and Swaziland. The median increase in relative abundance appears to be 11.27, an eleven-fold increase since SABAP1 (Table 4.1). For 205 out of the 242 grid cells where large increases in abundance have been recorded, the reporting rate was below the median for Marsh Warbler during SABAP1.

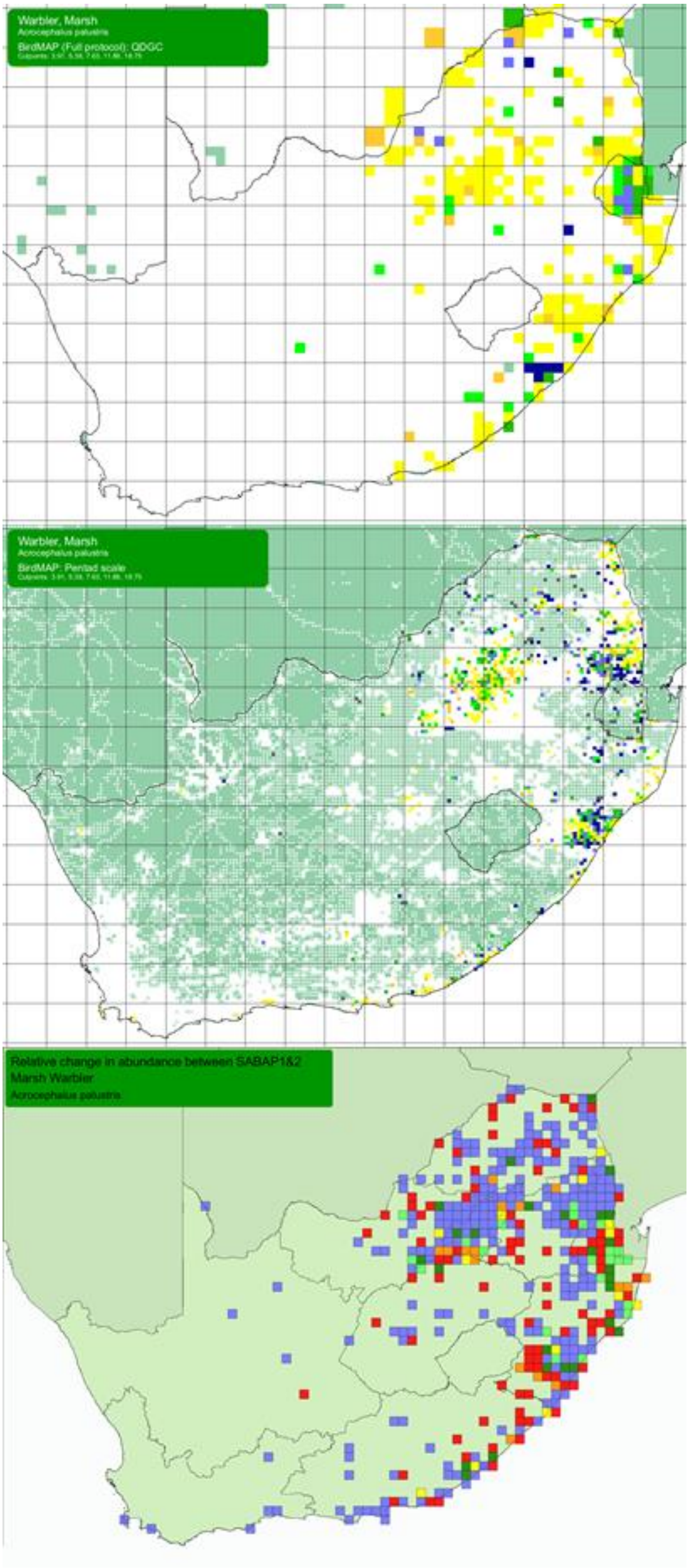

Figure 4A.7 Maps for the Marsh Warbler.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

The Marsh Warbler breeds in the temperate regions (i.e. middle latitudes) of Europe and western Asia. Its range stretches from the English Channel, which separates southern England from northern France, to about 70° east (Dyrcz 2006). It mainly occupies areas with a continental climate. Continental climates are dry with cold winters and hot summers. However, the Marsh Warbler has also been recorded in Britain and northern France during the breeding season (Dyrcz 2006). Marsh Warblers are associated with lowlands, but they occur at altitudes of up to 3000 m in Georgia, eastern Europe. It has expanded its range into northern Europe with increases in abundance recorded in Scandinavia and north-west Russia (BirdLife International 2016b).

Marsh Warblers like dense thickets and tangled undergrowth in woodland habitats, as well as forest edges and sometimes found in gardens (Hockey et al. 2005). In Europe, they favour habitats with rank scrubland and trees, especially vegetation like nettles *Urtica* sp., meadowsweet *Filipendula* sp., and brambles *Rubus fruticosus*. Marsh Warblers also occur in abandoned fields with secondary growth (BirdLife International 2016b). The Marsh Warbler's habitat preference suggests that it would benefit from bush encroachment.

Thus two factors drive the increase in abundance of Marsh Warblers: range expansion in breeding grounds, and bush encroachment both in the breeding grounds and non-breeding grounds. However, there is likely to be a third factor at play for this species too. During SABAP2, Marsh Warblers were identified far more readily than during SABAP1; this is one of the species that has benefitted massively from improvements in field guides, and most notably the arrival of books such as Peacock (2012).

Willow Warbler

Analysis

Willow Warblers were concentrated towards the north-west as well as Swaziland during SABAP1 (Figure 4A.8). There has been a shift of the Willow Warbler's core range towards the east and along the coastal and central Kwazulu-Natal Province since SABAP1 (Figure 4A.8).

Table 4A.7 Summary of changes in the relative abundance of the Willow Warbler between SABAP1 and SABAP2 (Figure 4A.8, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	122	177	299	27.1
ORANGE	20	113	133	12.1
YELLOW	21	73	94	8.5
LIGHT GREEN	29	73	102	9.2
DARK GREEN	62	92	154	14.0
BLUE	294	27	321	29.1
Total	548	555	1103	100

Using the criteria for inclusion of this study, the Willow Warbler analysis was based on 1103 grid cells. It showed large increases between SABAP1 and 2 in 321 (29.1%) grid cells and moderate increases in 154 (14.0%) grid cells (Table 4A.7). It shows large decreases in abundance in 299 (27.1%) grid cells and moderate decreases in 133 (12.1%) grid cells (Table 4A.7). Overall it is showing a trend increase for 43.1% of its range in South Africa, Lesotho and Swaziland. Their median increases in relative abundance is 1.09 (9%) (Table 4.1). For the 321 cells showing very large increases (shaded blue), 294 are in grid cells where the reporting rate during the first bird atlas was below the median for Willow Warblers.

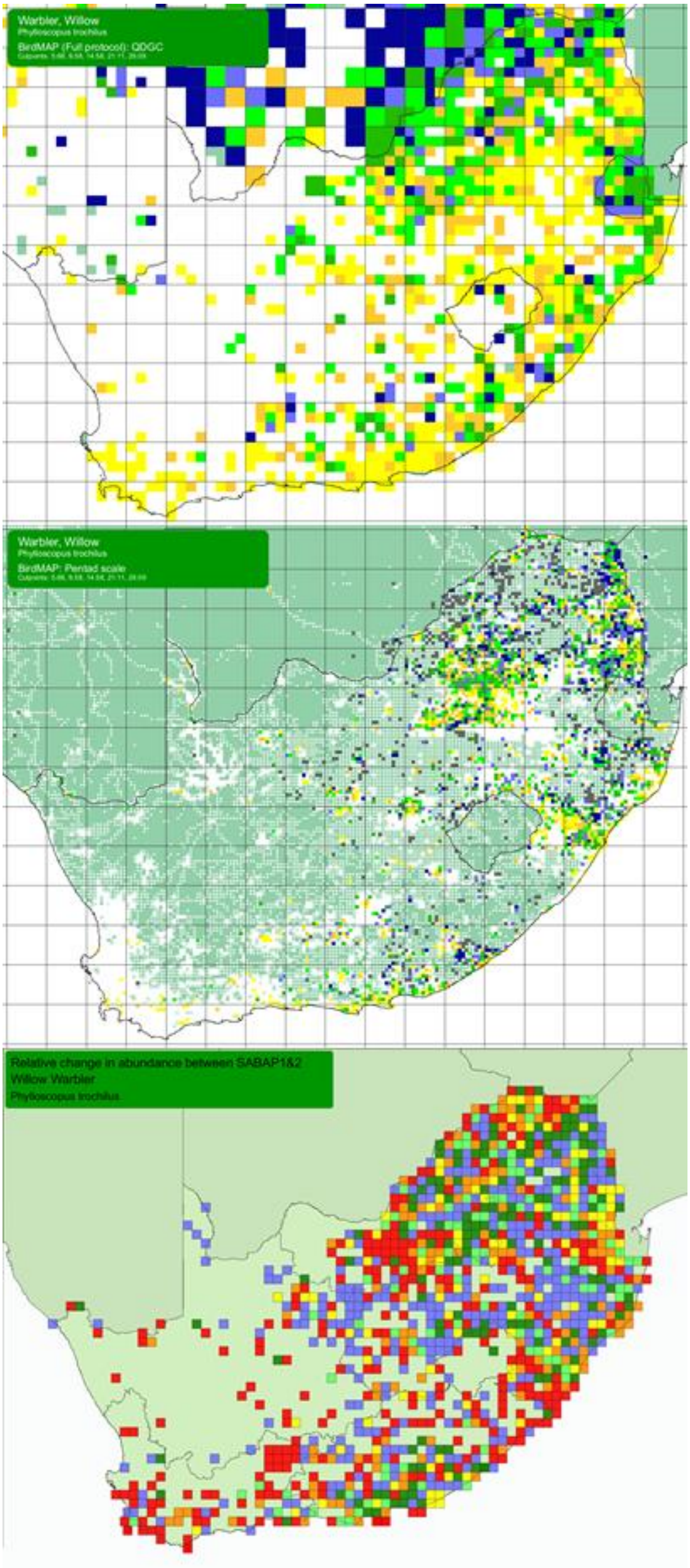

Figure 4A.8 Maps for the Willow Warbler.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

Willow Warblers are very common and widespread, spending the northern hemisphere breeding season throughout northern and temperate Europe as well as Asia (Baker 1997). Their breeding range extends from Ireland to eastern Siberia along the Anadyr River (Baker 1997). The Willow Warbler has a strong migration pattern, with almost the whole population spending the northern winter in sub-Saharan Africa (Hockey et al. 2005). Willow Warblers breeding in western Europe migrate mainly to western Africa, and those migrating to southern Africa breed in eastern Europe and Asia.

In the northern hemisphere, it occurs in open woodlands with trees and suitable ground cover, including birch, alder, and willow habitats, which it uses as nesting sites (Baker 1997). The nest is usually located close to the ground in low vegetation (Baker 1997). Like most members of the Sylviidae family, the Willow Warbler is insectivorous. Willow Warblers forage for insects by gleaning from foliage in the canopy as well as in shrubs near the ground (Hockey et al. 2005).

In the southern hemisphere, Willow Warblers make use of a wide range of woodland habitats (Hockey et al. 2005). They are found in closed and open *Vachellia* savanna, broad-leaved woodlands, riverine woodland, parks and gardens (Hockey et al. 2005). Their habitat preference indicates that they most likely benefit from an increase in woody cover. And this is reflected in their increase in abundance since SABAP1 (Figure 4A.8).

Of the 10 species considered here, the Willow Warbler is the one that is closest to stable, with a modest increase of 0.39% per year between SABAP1 and 2 (Table 4.2).

White Stork

Analysis

The core of the White Stork's range during SABAP1 was inland of the eastern coastal plain of South Africa, including Lesotho, mainly along the escarpment (Figure 4A.9). Compared to SABAP1, their core range has contracted considerably during SABAP2, with a small core range east and south-east of Lesotho (Figure 4A.9). Overall White Storks have undergone a significant decline in abundance since SABAP1.

Table 4A.8 Summary of changes in the relative abundance of the White Stork between SABAP1 and SABAP2 (Figure 4A.9, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	265	407	672	57.6
ORANGE	78	106	184	15.8
YELLOW	37	38	75	6.4
LIGHT GREEN	30	30	60	5.1
DARK GREEN	42	12	54	4.6
BLUE	120	1	121	10.4
Total	572	594	1166	100

For the purposes of this study, there are 1166 qualifying grid cells. It shows a large decrease in 672 (57.6%) grid cells and a moderate decrease in 184 (15.8%) grid cells (Table 4A.8). Large increases have occurred in 121 (10.4%) grid cells and moderate increases in 54 (4.6%) grid cells (Table 4A.8). Overall the White Stork is showing a downward trend, having large or moderate decreases in 73% of the 1166 grid cells included in the study in South Africa, Lesotho and Swaziland. The analyses suggest that, during SABAP2, there were only 21% as many White Storks than during SABAP1 (Table 4.1). For the 672 grid cells showing very large decreases (shaded red), 407 (60.6%) are grid cells where the SABAP1 reporting rate was larger the median reporting rate for White Stork during SABAP1. This indicates large decreases in abundance in the core of the range of the species.

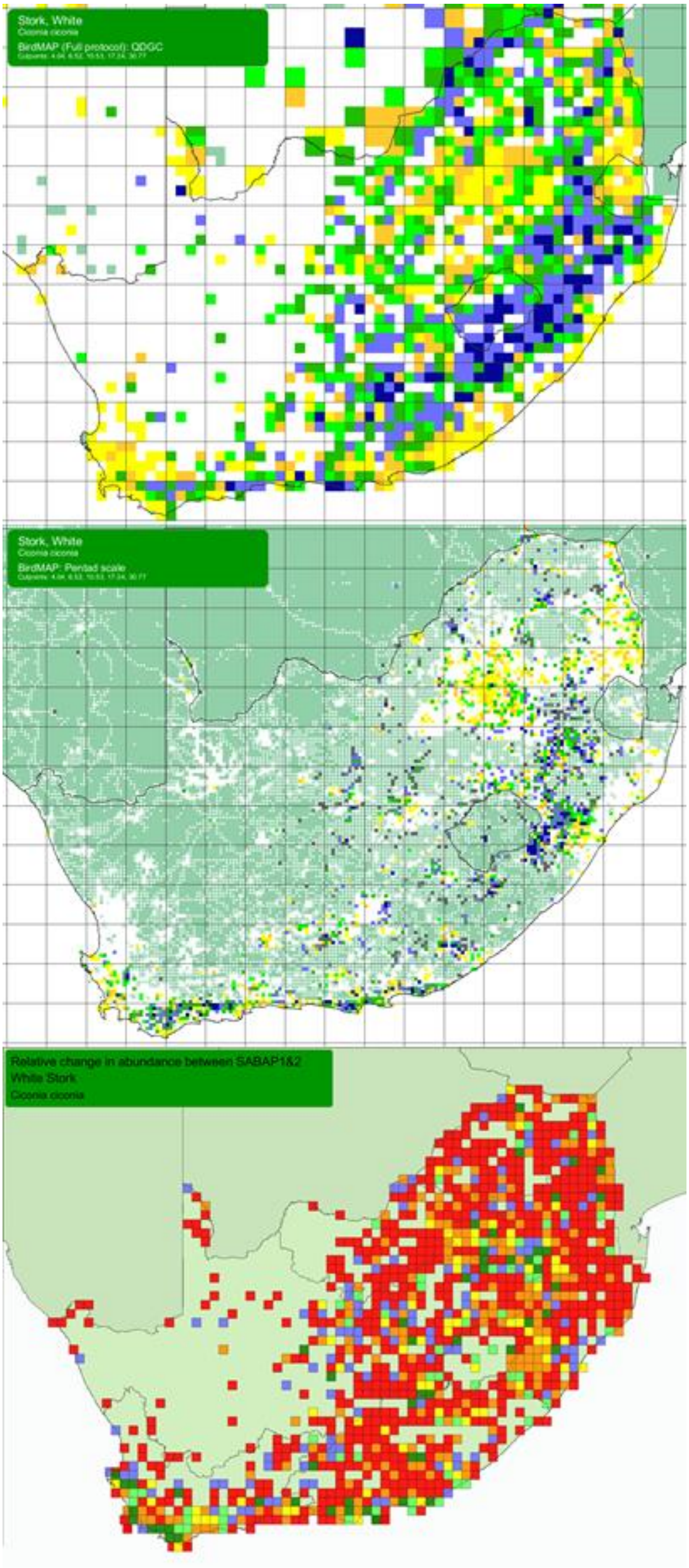

Figure 4A.9 Maps for the White Stork.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

Globally, the population of White Storks is thought to be increasing, although in some areas they have decreased (Wetlands International 2015). It has been estimated that the White Stork population in western Europe has increased substantially since 1980 (Vickery et al. 2014, EBCC 2015) (Table 4.2). White Storks inhabit open areas, generally avoiding regions with frequent cold, wet weather conditions or areas with large tracts of dense vegetation like forests or reedbeds (Hancock et al. 1992). Their preference for open habitats means that bush encroachment would impact them negatively, but bush encroachment in South Africa does not seem to be the overarching factor influencing White Stork populations. In South Africa, the vast majority of the population can be found in crop fields and pastures where they forage for insects and small invertebrates (Hockey et al. 2005).

In Africa, high rates of mortality have been recorded due to decreased prey availability owing to drought, desertification and the use of insecticides to control locust populations (Hancock et al. 1992). White Storks seem to be very sensitive to the use of pesticides and insecticides (Hockey et al. 2005). Mortalities have also been recorded where poisoned baits have been put out to kill large carnivores in farming areas (del Hoyo et al. 1992). Collisions with power lines remain a big threat (Hancock et al. 1992).

The breeding range of the White Stork has its south-eastern limit in the Ukraine. The range does not extend into far eastern Europe. Most ring recoveries of White Storks in southern Africa are of birds ringed as nestlings in Europe (Underhill et al. 1999). The majority come from eastern half of the breeding range. Little ringing of White Storks has been done in the south-eastern part of the breeding range, in south-eastern Russia and the Ukraine, but it is likely that these storks migrate to South Africa. The large decrease of White Storks in South Africa is most likely to be attributable to habitat change on the breeding grounds. White Storks are likely to have been severely and negatively impact by the abandonment of collective farms at the end of the former Soviet Union. The replacement of open agricultural fields, for both crops and pasture, with shrub-encroached landscapes is a possible cause of the major decrease of White Storks suggested by the range-change map and associated statistics.

Barn Swallow

Analysis

The core of the Barn Swallow's range was in the north-west of South Africa (North-West Province, Limpopo Province, and parts of the Northern Cape) during SABAP1, and along the eastern coastline (Figure 4A.10). The SABAP2 distribution map shows a shift of the core range towards the east as well as farther along the coast from the east towards the west into the Western Cape Province (Figure 4A.10).

Table 4A.9 Summary of changes in the relative abundance of the Barn Swallow between SABAP1 and SABAP2 (Figure 4A.10, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	103	100	203	11.8
ORANGE	68	165	233	13.6
YELLOW	86	202	288	16.8
LIGHT GREEN	150	253	403	23.5
DARK GREEN	256	128	384	22.4
BLUE	192	11	203	11.8
Total	855	859	1714	100

The Barn Swallow analysis is based on 1714 grid cells. It shows large decreases in abundance in 203 (11.8%) grid cells and moderate decreases in 233 (13.6%) grid cells (Table 4A.9). It also shows large increases in 203 (11.8%) grid cells and moderate increases in 384 (22.4%) grid cells (Table 4A.9). Of the blue grid cells (large increase), 192 of these are cells where the reporting rate was below the median during SABAP1 (Table 4A.9). The Barn Swallow has a larger proportion of light green grid cells, 23.5%, than any of the other eight species considered here. These are grid cells where the population is considered to have remained stable and increased slightly. Overall, the Barn Swallow is estimated to have increased in abundance by 15% between SABAP1 and SABAP2 (Table 4.1). 192 of the 203 grid cells where large increases have been recorded (and 256 of the 384 grid cells with moderate increases) are grid cells where the reporting rate during SABAP1 was below the median for Barn Swallows. This suggests that the Barn Swallow is increasing in abundance in grid cells which were not part of the core of its range during SABAP1.

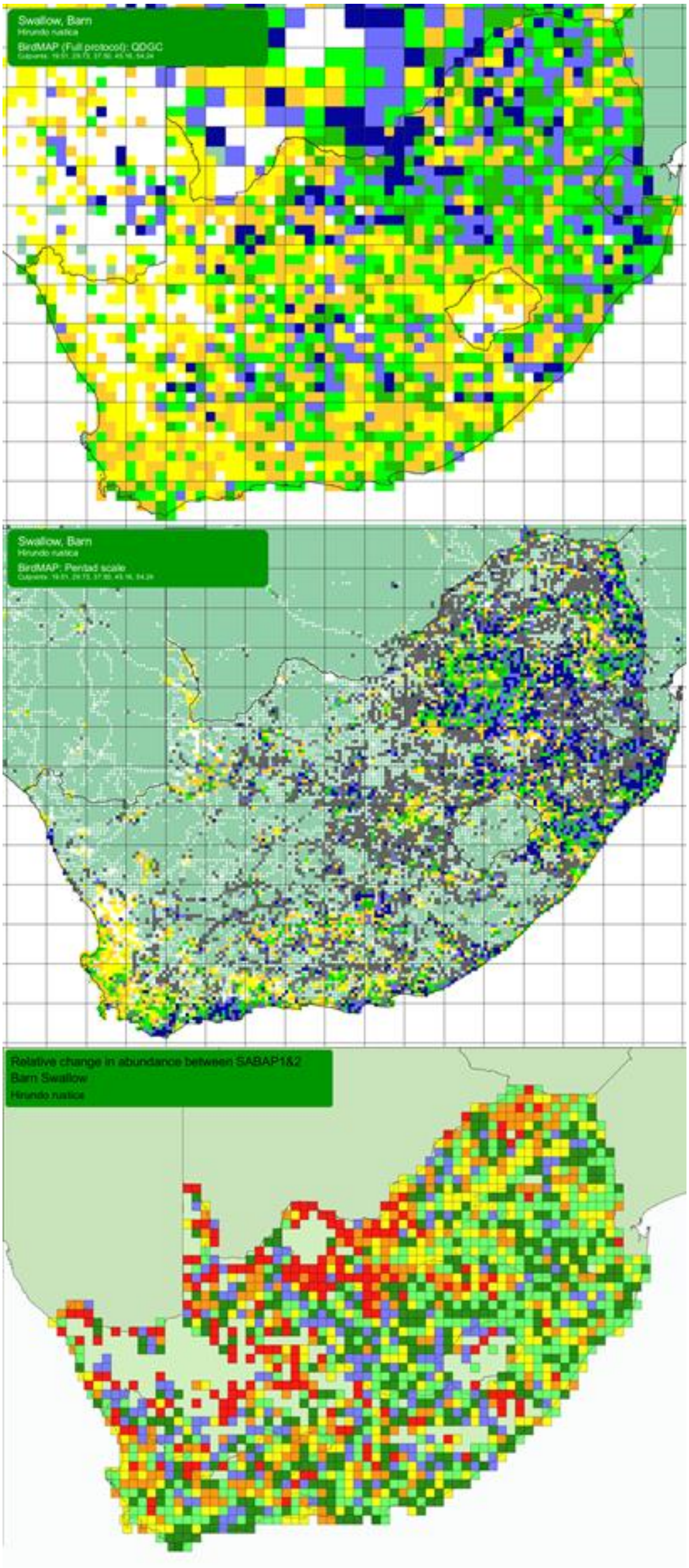

Figure 4A.10 Maps for the Barn Swallow.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

Barn Swallows have a very large range globally. Their breeding grounds stretch from North America to Europe and Asia (Hockey et al. 2005). During the non-breeding season, they migrate south to Africa, South America and southern Asia. European birds "over-winter" in sub-Saharan Africa (Hockey et al. 2005), but some individuals have been recorded spending the non-breeding season in southern and western Europe every year (Snow and Perrins 1998). In southern Africa, Barn Swallows can occur in any habitat, but they are uncommon in arid, semi-arid and high altitude areas like Lesotho (Earlé 1997). They are far more common in the higher rainfall areas in the east of southern Africa and South Africa (Earlé 1997). The SABAP1 vegetation analysis shows their preference for miombo, moist woodland as well as mixed grasslands. An increase in woody cover might be benefitting them, but this needs further investigation. There has been a definite shift of their core range to the east in South Africa (Figure 4A.10), which is where most of the bush encroachment has occurred.

The main threat facing Barn Swallows is the intensification of agriculture. Changes from traditional expansive farming practices, for example in the beef and milk production industry, to more intensive farming methods has resulted in a loss of suitable foraging areas (BirdLife International 2016a). Barn Swallows are also sensitive to changes in climate and local weather changes. Consistent bad weather on their non-breeding grounds in the southern hemisphere as well as the breeding grounds in the northern hemisphere has an impact on their breeding success (BirdLife International 2016a).

Steppe Buzzard

Analysis

The core of the Steppe Buzzard's range during SABAP1 was concentrated in the Western Cape Province of South Africa, the interior of the country (Free State and Eastern Cape Province), and along the eastern coast (Figure 4A.11). For SABAP2, its core range has fragmented, with reporting rates in the interior of the country decreasing strongly compared to SABAP1. The core range for SABAP2 is located in the Western Cape and KwaZulu-Natal Province (Figure 4A.11).

Table 4A.10 Summary of changes in the relative abundance of the Steppe Buzzard between SABAP1 and SABAP2 (Figure 4A.11, bottom map). Numbers shown are counts of grid cells showing six categories of increase/decrease of relative abundance (for colour codes for categories, see text). The columns headed "<median" and ">median" provide counts of grid cells in the range change map in relation to the median reporting rate for the species in SABAP1. The final column gives the percentage of grid cells in each category of increase or decrease.

Grid Cell Colour	<median	>median	Total	Percentage
RED	142	212	354	24.8
ORANGE	65	226	291	20.3
YELLOW	74	129	203	14.2
LIGHT GREEN	88	98	186	13.0
DARK GREEN	147	42	189	13.2
BLUE	199	8	207	14.5
Total	715	715	1430	100

Steppe Buzzards have been recorded in 1430 grid cells. It shows very large decreases in 354 (24.8%) grid cells and large decreases in 291 (20.3%) grid cells (Table 4A.10). Very large increases have occurred in 207 (14.5%) grid cells and large increases in 189 (13.2%) grid cells (Table 4A.10). Overall the Steppe Buzzard is showing a downward trend, having decreased in more than 45% of its range in South Africa, Lesotho and Swaziland. There are only about 77% as many Steppe Buzzards now as during SABAP1 (Table 4.1) For the 354 grid cells showing very large decreases (shaded red), 212 (59.9%) are grid cells where the SABAP1 reporting rate was above the median reporting rate for Steppe Buzzard during the first bird atlas.

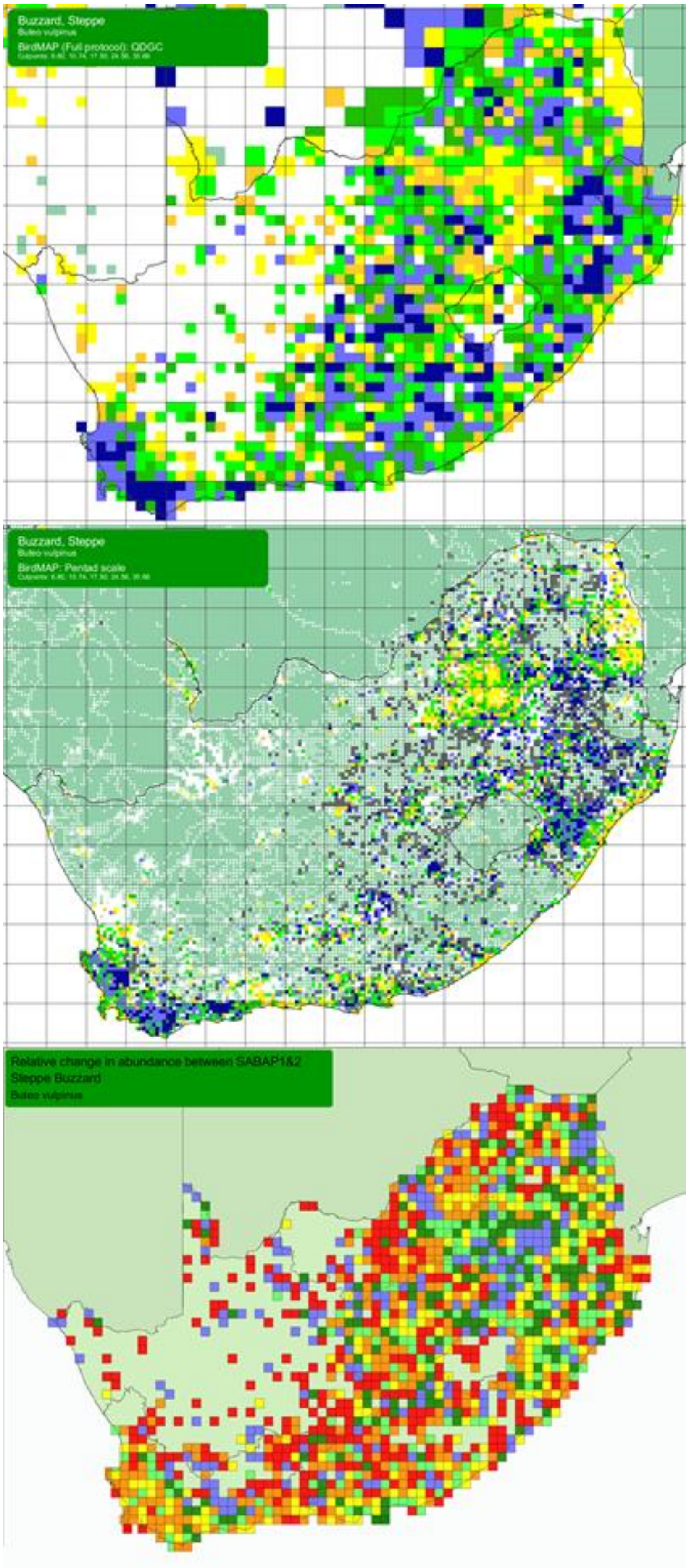

Figure 4A.11 Maps for the Steppe Buzzard.
Top: SABAP1 distribution.
Middle: SABAP2 distribution.
Bottom: Range-change map. See text for further details of interpretation.

Background

The Steppe Buzzards occurring in southern Africa have been demonstrated, by ring recoveries, to be spread across Eurasia, from 24°E in southern Finland to 93°E in Siberia, in northcentral Asia (Oatley et al. 1998). The name Steppe Buzzard is, as pointed out by Moreau (1972), a misnomer because in this eastern half of its range, it breeds mainly in the taiga, the coniferous forests which lie north of the steppes and south of the tundra (Moreau 1972). According to Hockey et al. (2005), Steppe Buzzards prefer open habitats, like grasslands, open savanna, and open woodland. They have also been recorded in croplands (Hockey et al. 2005). This suggests that habitats that have become too bush encroached will be unfavourable for Steppe Buzzards and they might avoid such areas completely. Increased woody cover could have a negative impact on this species.

In Europe, the main threats have been persecution, either by poisoned bait or shootings, and habitat loss (IUCN 2017). Steppe Buzzards are also very vulnerable to the impacts of wind turbines and further wind energy developments across Europe (STRIX 2012).