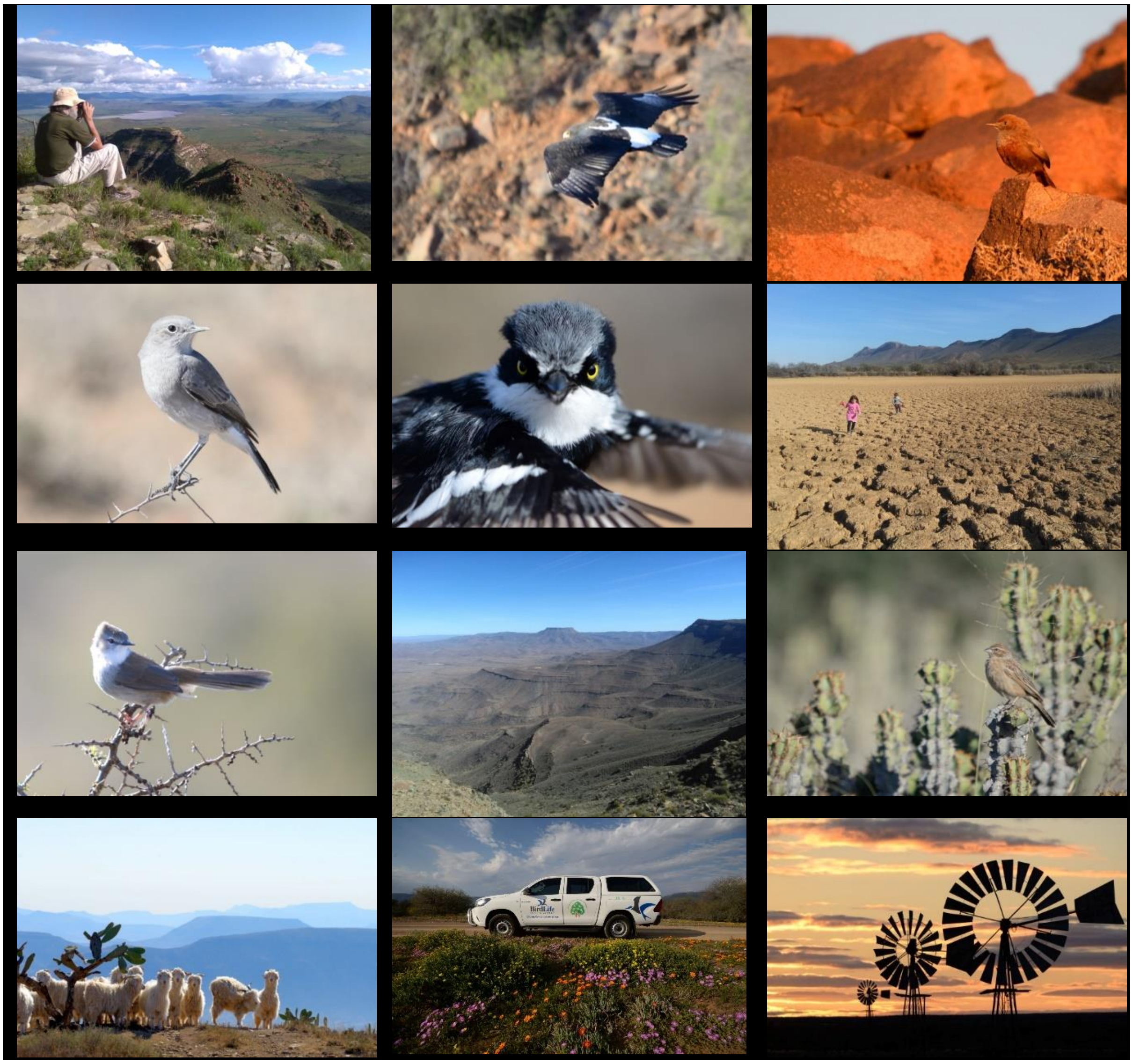
The Karoo Birds Research and Conservation Project

Final Project Report based on fieldwork conducted through the Karoo south of the Orange River during 2017 and 2018

A BirdLife South Africa conservation project by Alan Lee and Dale Wright.
Report by: Alan Lee

January 2019

Giving conservation wings



Summary

The Karoo biome is a vast arid zone environment covering 26% of South Africa, as well as Namibia, and is home to 11 endemic bird species. The Karoo Birds Project was a BirdLife South Africa initiative run from 2017-2018, which aimed to provide a conservation assessment by obtaining data on population size, range and population trends primarily of the Karoo endemic bird species. This report was obtained through a point count and atlasing project across the Karoo region south of the Orange River, South Africa. This was partly run in conjunction with the Karoo BioGaps project. The South African National Biodiversity Institute's (SANBI) Karoo BioGaps project aimed to gather foundational biodiversity data to support the impact assessments for Shale Gas and other infrastructure development projects in the Karoo basin. During 2017 and 2018 we conducted 2854 point counts across 150 pentads, mostly from end of July to October, largely corresponding to the late winter to early spring period. We found that avian species richness and bird abundance increased eastwards, mostly explained by increasing overall vegetation height, but accompanied by increasing grass cover and decreasing sand cover. In contrast, Karoo endemic bird species richness decreased eastwards, negatively correlated with increasing grass and acacia tree cover. Density and species richness were especially high around water locations and farmhouses, and we found that the presence of many species to be influenced by water, a surprising result for an arid environment. We calculated density estimates for 78 bird species. We also explored the relationship between bird density and reporting rates, finding a good fit for 15 of the 20 most common species between reporting rates and cluster size. A community model suggested that overall mean reporting rate was well explained by the log of density and log of bird mass. This allowed us to estimate population of the Karoo endemic Sclater's Lark, for which too few encounters were obtained to use standard distance sampling approaches. Further research on this species is required. Threats identified to ecological integrity included over-grazing, warming due to climate change, and the use of poison for control of problem animals. Overall currently, despite several drought years across the Karoo and a myriad of threats, populations of the Karoo endemic bird species appear stable.

Filling biodiversity information gaps

Karoo BioGaps Project

Introduction

The Karoo

The Karoo *sensu* lato describes the arid south-western zone of South Africa and consists of two botanically distinct biomes: the Succulent Karoo with predominantly stable winter rainfal, and Nama-Karoo with predominantly summer rainfall where amounts vary highly between years (Dean and Milton 1999). The Nama and Succulent Karoo together cover 454 027 km^2 (WWF), approximately 25% of SA and at least 25% of Namibia, with a narrow band adjacent to the Namib desert stretching all the way to southern Angola. As this is an arid zone, annual rainfall is low (50 – 600mm) and is often highly localized, varying annually in amount and timing (Desmet and Cowling 1999). The variability of the rainfall and long dry spells or severe droughts create a mosaic so that high and low resource areas occur as patches in the landscape. The Karoo also experiences a dramatic range of temperatures, from frost and snow prone high-altitude areas, to extremely hot central regions bordering the Kalahari Desert. Temperatures recorded during counts ranged from -4 to 33°C during this survey. Temperatures also fluctuate extremely during the day, with a range of 26 degrees (min = 6.1, max = 32.4) recorded for 4-September-2017.

Birds of the Karoo

Karoo (used here to mean both Succulent and Nama Karoo biomes, Figure 1) is rich in species: over 407 bird species have been recorded in the Succulent and Nama-Karoo, of which 294 species are considered typical of the region (Dean 1995). The Nama-Karoo has a high species richness of nomadic birds, and both the Succulent and Nama-Karoo have high species richness of larks (Alaudidae) compared with other biomes. Resident species of birds tend to maintain low densities and wait for rainfall events, whereas nomadic species search for high resource patches scattered in time and space, so that their respective densities likewise vary temporally and spatially (Dean 1995).

Vernon (1999) considers the following 8 species to be endemic to the Karoo: Karoo Korhaan, Karoo Lark, Red Lark, Sclater's Lark, Black-eared Sparrowlark, Karoo Eremomela, Cinnamon-breasted Warbler and Namaqua Warbler (Table 1). The subsequent splitting of the Karoo and long-billed lark complex means that Karoo Long-billed Lark can be added to this list, as well as Barlow's Lark for a total of 10 clear Karoo endemic bird species. An examination of Southern African Bird Atlas Project (SABAP) ranges suggests the following have core ranges strongly centred on the Karoo: Cape Long-billed Lark, Large-billed Lark, Ludwig's Bustard, Grey Tit, Sickle-winged Chat, Karoo Chat, Karoo Scrub-Robin, Rufous-eared Warbler, Black-headed Canary, Layard's Titbabbler and Pale-winged Starling. In addition to this set of Karoo 'specials' a variety of arid zone species contain at least 50% of their core range in the Karoo, e.g. Fairy Flycatcher, Karoo Prinia, Grey-backed Cisticola, Pririt Batis, White-throated Canary, Namaqua Sandgrouse, Namaqua Dove, Dusky Sunbird. Of the species reliant on the Karoo, two are considered species of IUCN conservation concern: Ludwig's Bustard (Endangered) and Red Lark (Vulnerable), with Sclater's Lark listed as Near Threatened.

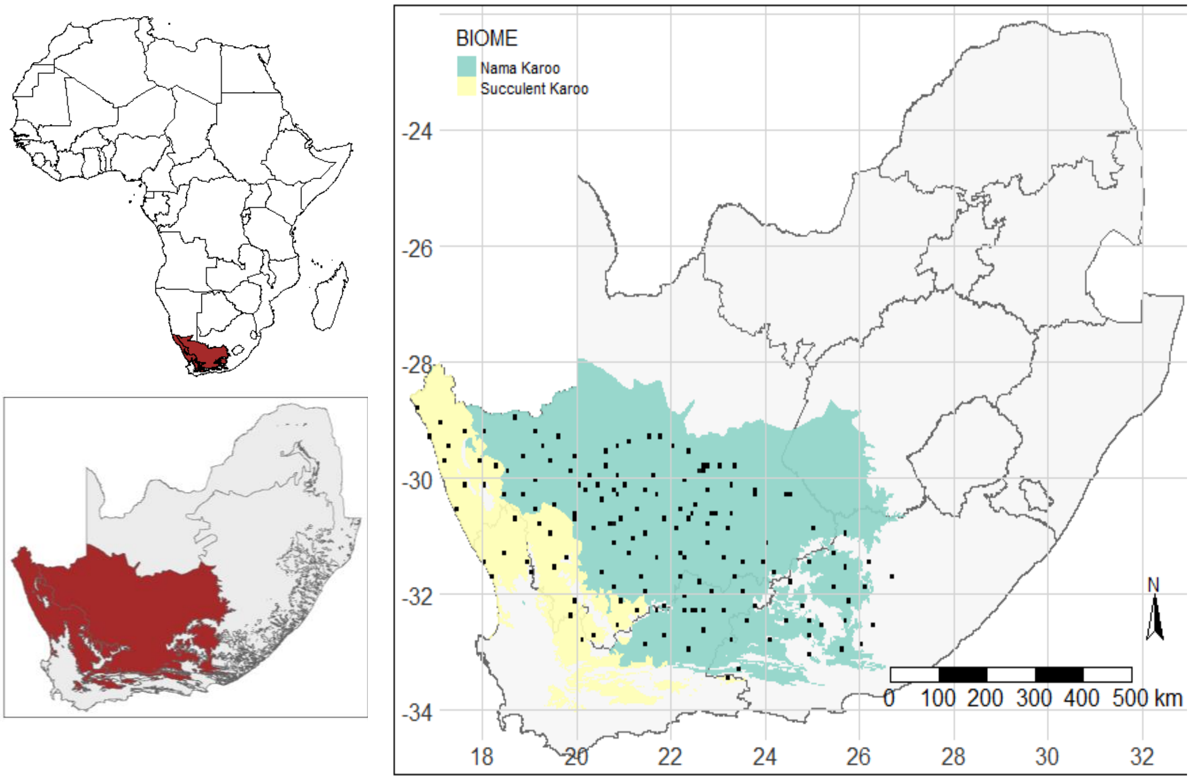


Figure 1: The Karoo biomes in Africa (inset 1, according to WWF); differentiated into Nama Karoo and Succulent Karoo in South Africa (main image), following Mucina and Rutherford (2006). Black squares indicate pentads where point counts were conducted during 2017 and 2018.

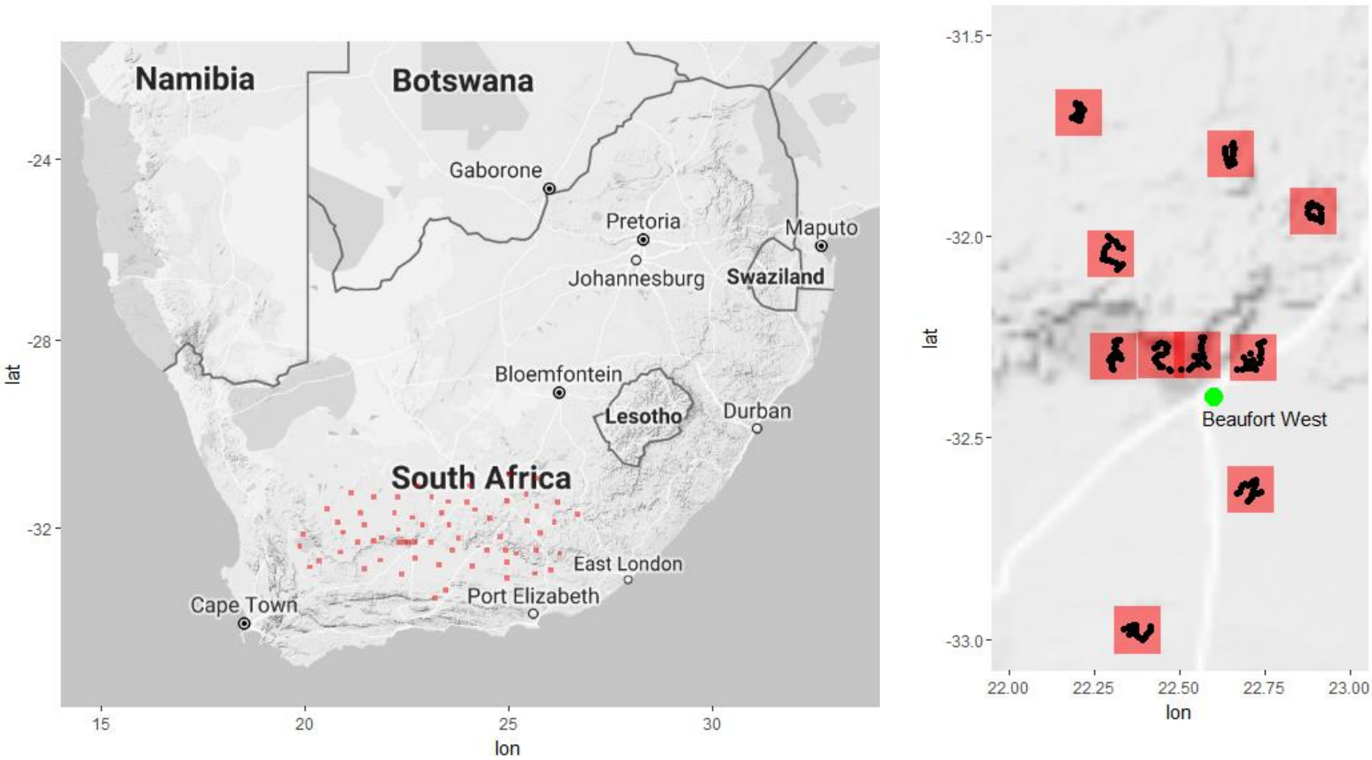
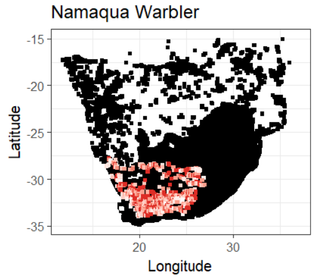


Figure 2: Survey map with the location of Karoo BioGaps pentads indicated as red squares and surveyed during 2017, while the right panel indicates an example of point count locations (black dots) within pentads for the area around Beaufort West.

Table 1: Summary statistics for the 10 Karoo endemic bird species from SABAP data (summarised in (Lee et al. 2017a), but presenting new data for Karoo Korhaan, Barlow's, Cape and Karoo Long-billed Larks). Range maps are based on SABAP2 coverage as of end 2016: black = squares with coverage and species not recorded, white = no coverage, with density ranging from light pink (low reporting rate) to red (high reporting rate).

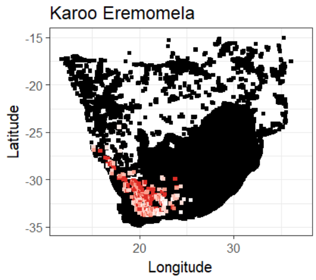
Namaqua Warbler
Phragmacia substriata

Mass = 12 g
Range = 214 000 km^2
Pentad area = 52 000 km^2
Least Concern



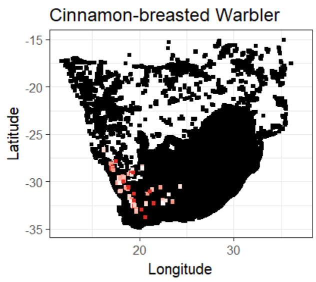
Karoo Eremomela
Eremomela gregalis

Mass = 8 g
Range = 99 000 km^2
Pentad area = 19 000 km^2
Least Concern



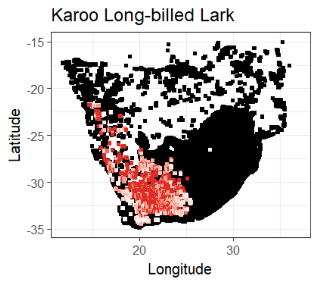
Cinnamon-breasted Warbler
Euryptila subcinnamomea

Mass = 12 g
Range = 33 000 km^2
Pentad area = 5 400 km^2
Least Concern



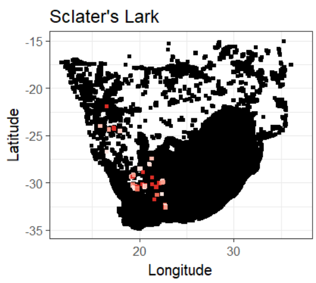
Karoo Long-billed Lark
Certhilauda subcoronata

Mass = 45 g
Range = 795 339 km^2
Pentad area = 108 135 km^2
Least Concern



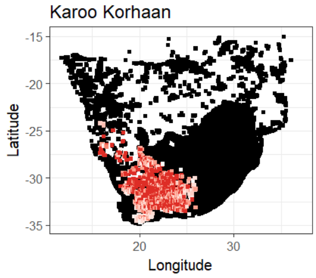
Sclater's Lark
Spizocorys sclateri

Mass = 20 g
Range = 179 000 km^2
Pentad area = 3 200 km^2
Near Threatened



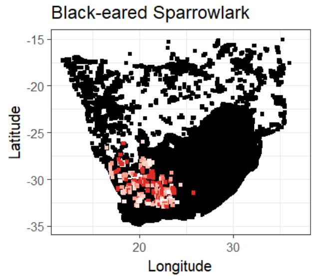
Karoo Korhaan
Eupodotis vigorsii

Mass = 1.6 kg
Range = 473 121 km^2
Pentad area = 119 000 km^2
Least Concern



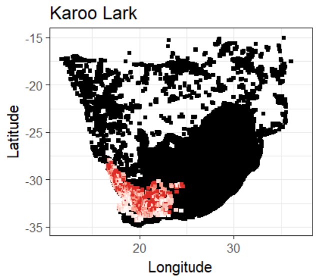
Black-eared Sparrow-lark
Eremopterix australis

Mass = 14 g
Range = 87 000 km^2
Pentad area = 27 000 km^2
Least Concern
Photo: Warwick Tarboton



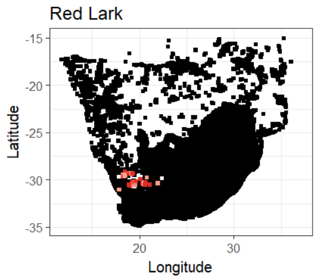
Karoo Lark
Calendulauda albescens

Mass = 29 g
Range = 176 000 km^2
Pentad area = 25 000 km^2
Least Concern



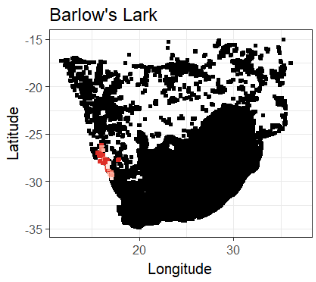
Red Lark
Calendulauda burra

Mass = 37 g
Range = 16 700 km^2
Pentad area = 4 400 km^2
Vulnerable



Barlow's Lark
Calendulauda barlowi

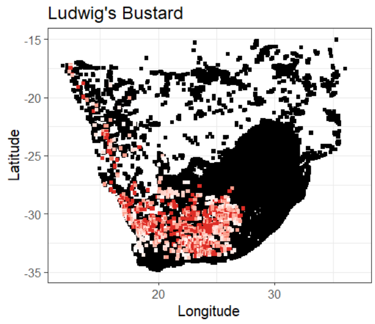
Mass = 30 g
Range = 18 200 km^2
Pentad area = 5 100 km^2
Least Concern



Karoo Specials (>75% of range occurs in the Karoo biomes)

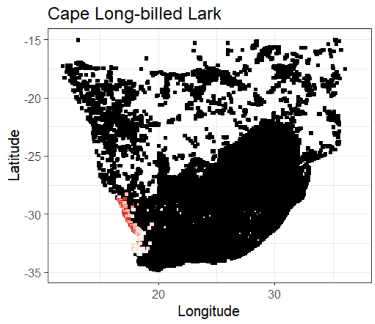
Ludwig's Bustard
Neotis ludwigii

Mass = 4 kg
Endangered
Pentad area = 98 010 km^2



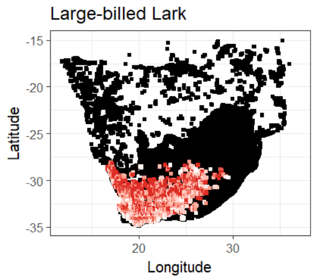
Cape Long-billed Lark
Certhilauda curvirostris

Mass = 45 g
Range = Not quantified*
Pentad area = 12 636 km^2
Least Concern



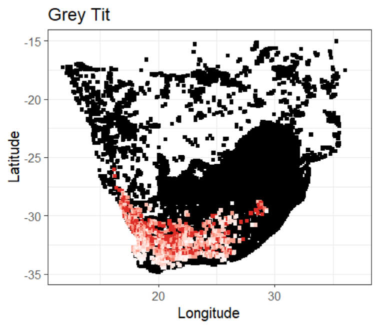
Large-billed Lark
Galerida magnirostris

Mass = 45 g
Range = 401 000 km^2
Pentad area = 132 000 km^2
Least Concern



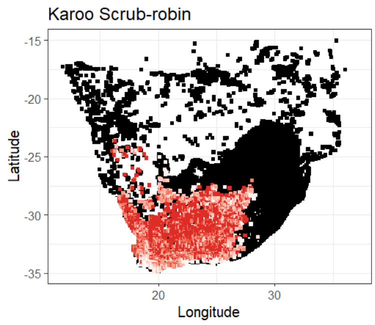
Grey Tit
Melaniparus afer

Mass = 20 g
Least Concern
Pentad area = 91 206 km^2



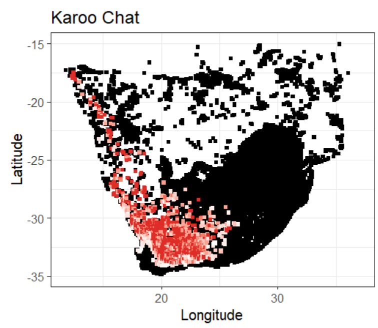
Karoo Scrub Robin
Cercotrichas coryphoeus

Mass = 22 g
Least Concern
Pentad area = 338 742 km^2



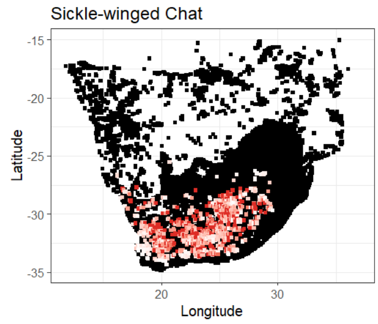
Karoo Chat
Cercomela schlegelii

Mass = 21 g
Least Concern
Pentad area = 139 158 km^2



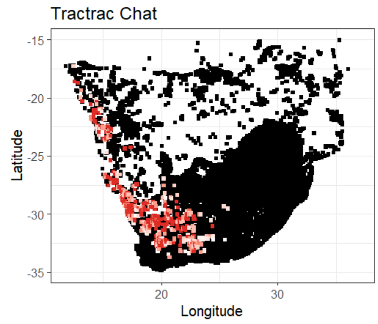
Sickle-winged Chat
Emarginata sinuate

Mass = 20 g
Least Concern
Pentad area = 96 147 km^2



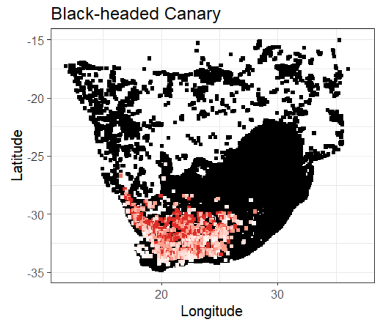
Tractrac Chat
Emarginata tractrac

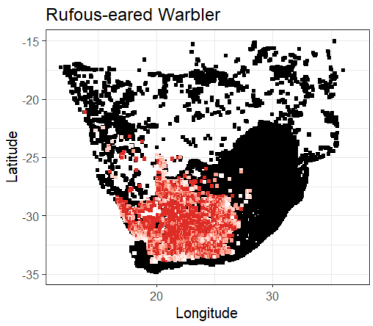
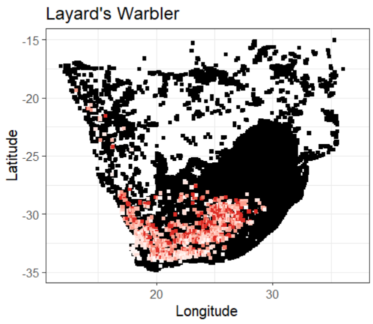
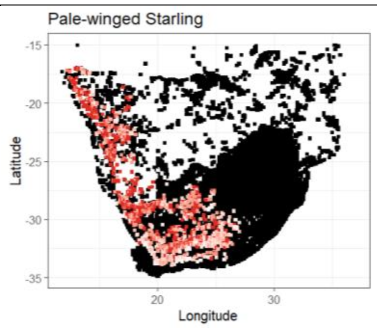
Mass = 26 g
Least Concern
Pentad area = 52 893 km^2



Black-headed Canary
Serinus alario

Mass = 12 g
Least Concern
Pentad area = 96 714 km^2



	**Rufous-eared Warbler** *Malcorus pectoralis* Mass = 10 g Least Concern Pentad area = 256 770 km^2	
	**Layard's Warbler (Titbabbler)** *Sylvia layardi* Mass = 13.5 g Least Concern Pentad area = 96 795 km^2	
	**Pale-winged Starling** *Onychognathus nabouroup* Mass = 97 g Least Concern Pentad area = 121 986 km^2	

Landscape change: Threats and opportunities

Historically, the primary threat to avifauna was deemed to be as a result of grazing-induced changes in species richness of plants and structure of habitats, as these appeared to be an important determinant of species richness of birds (Dean 1995). Dean (1995) noted that species richness of birds was highest on lightly grazed rangelands, intermediate on moderately grazed rangelands and lowest on the heavily grazed rangelands. Nest site preferences of ground-nesting and shrub-nesting birds may have been influenced by grazing mammals in Karoo shrublands, as birds tended to select sites in or under plants that are not preferred by mammals for food.

However, over the last two decades multiple new threats have emerged across the Karoo landscape. Pylons and the electric grid infrastructure pose a major threat to the long term viability of populations of Ludwig's Bustard, which are prone to collisions along the cable systems (Shaw et al. 2015). Alternative energy development in the form of wind turbines and solar energy facilities is experiencing rapid growth currently in South Africa, and various bird species, dominated by raptors, have been recorded as fatalities by wind-turbine strikes (Ralston in prep). Climate change is resulting in rapid warming of South Africa's arid environments and is resulting in higher rates of extreme weather events, all of which take their toll on avifauna (Cunningham et al. 2013a, Cunningham et al. 2013b, du Plessis et al. 2012, McKechnie and Wolf 2010). At the same time, climate change in association with telephone line infrastructure have been given as the reason for the spread of Pied Crows into new areas (Cunningham et al. 2016).

In addition to the above documented threats, there are new and emerging threats where the impacts have been poorly quantified, including Uranium mining, solar energy facilities and shale gas extraction i.e. fracking. Given the scale of potential development in the Karoo, there is concern that there are few formally protected areas in this biome: in fact it has the lowest percentage protected of any of South Africa's biomes. There is also concern that protected areas in the Karoo are markedly skewed to the higher rainfall areas, and are particularly inadequate for the protection of the endemic and nomadic species of birds (Dean 1995).

However, not all human influence is necessarily bad: the spread of agriculture and associated infrastructure has also meant that water availability is a lot more widespread and the supply is a lot more consistent in recent decades. Watering points for livestock are usually maintained, providing predictable water sources year round, shaping bird communities over relatively small spatial scales in an arid environment (Abdu et al. 2018). Increased availability of pasture and other resources e.g. trees (Archer 2000) likely also provides food and nesting opportunities for bird species, like Egyptian Goose and Blue Crane (Mangnall and Crowe 2003). Farmsteads are structurally heterogenous, providing a wider range of nesting or food resources (Child et al. 2009). None-the-less, it is unclear how birds of the Karoo are responding to the multitude of changes presently occurring.

Aim

The aim of the Karoo Birds Project is to undertake a conservation assessment of the special avifauna of the Karoo biome. This has been done by quantifying baseline information useful for making informed conservation decisions on the status of each species i.e species geographic range, population size, population trends, and threat identification.

The aim of the current report is to present our state of knowledge based on surveys conducted in the Karoo during 2017 and 2018, bearing in mind that this is a snap-shot and that populations of nomadic species may differ dramatically from year to year depending on local conditions. This information serves as baseline for publications on these themes, currently either submitted or in preparation, as well as a habitat management guidelines document. Knowledge gaps and recommendations for future research are further provided.

We present patterns of bird species richness and abundance from point counts in relation to natural and environmental covariates. In addition, for species for which sufficient encounters were obtained we calculate density estimates, and then we explore the relationship between SABAP2 reporting rate and density. We comment on species vulnerable to contaminated water sources, and present information on SABAP2 population trends, population size and range which are fundamental to making decisions regarding species conservation status. We present further information on species presence in relation to land condition and other environmental variables; and provide range maps for selected species based on machine learning methods.

Methods

Study area

The area of the Karoo that was covered in this study falls within South Africa, with sampling across the biome, except for Karoo in the Free State (east of the Orange-River) where the Karoo transitions into savanna or grassland biomes (Figure 1). Further sampling was restricted by time and budget constraints. However, the sampling can be considered comprehensive in terms of the core biome areas in South Africa, covering all regions with high Karoo endemic species richness.

Sampling design: point counts to determine densities and landscape association variables

To obtain information on patterns of species richness and abundance, we conducted point counts in pentads. Pentads are geographical areas of approximately 9x9 km^2, with variation in area depending on latitude. During 2017 we surveyed pentads in the southern Karoo, mostly those identified by the Karoo BioGaps project (Figure 2). The Karoo BioGaps project aims to provide foundational biodiversity information to areas where shale-gas exploration concessions may be granted. Pentads were selected by the Karoo BioGaps team using latin hypercube sampling (McKay et al. 1979) to ensure spatially near-random sampling with adequate coverage of the main environmental gradients (temperature, rainfall) and included arid sites in Albany thicket and Grassland biomes (Figure 1). During 2018 surveys extended north of the Karoo BioGaps region into Namaqualand and Bushmanland regions, extending from the west coast of South Africa to the Orange River bordering the Free State province in the East.

We conducted 1192 point counts within 64 pentads during 2017 (Figure 2) and 1662 point counts in 86 pentads during 2018, for a total of 2854 counts in 150 pentads. Point counts were conducted using Distance Sampling techniques (Buckland et al. 2005). Distance sampling is a variation of plot sampling but where change in detection over distance from the observer is used to account for detectability. Point counts were of duration 10 minutes, aiming for 20 point counts within a 24 hour period. Point locations were spaced 500m to 1km apart, depending on terrain and access permission, as most pentads were on private land. An attempt was made to cover the width and breadth of each associated pentad, and to visit a range of altitudinal locations and point features: for example, an effort was made to conduct at least one count at a water source at each location if it became clear that random locations were not associated with water sources. GPS position was recorded, allowing spatial patterns of analysis (by latitude and longitude), as was altitude (meters above sea level). Period of surveys was from 21 February to 25 October 2017, with most surveys (76%) conducted in the late-winter to mid- spring period (late July – October), referred to here-on as the spring survey. All 2018 pentads were surveyed during this 'spring' period. While most counts were conducted by AL, DW conducted surveys in 4 pentads (2.5% of counts), while during 2018 Eric Herrmann also contributed to counts, conducting 28% of all point counts.

For each group of birds detected, the following information was recorded: time of detection since start, group size, method of detection (heard or seen only), bird activity related to distance sampling (perched or flying), and distance (m) was measured using a laser rangefinder to the centre of any group of birds, together with a compass bearing. If demography (male, female, juveniles) could be determined, this was recorded. Detailed activity was recorded for species with good viewings (marking any of the applicable categories: vigilant, calling, foraging, alarm calling, displaying, calling, drinking, within species aggression, between species aggression, resting, fleeing, nesting). We only summarise observations related to drinking behaviour in this report. Behaviours related to heat dissipation were also recorded, including: no heat dissipation, panting, wing-drooping, and shade seeking.

During 2017 at each point information was taken on vegetation cover from 16 functional plant group types. Each of these were also scored for percentage flower (0 = none to 100 = all branches of all plants in flower). However, incidence of flower presence was low (flowers of any species were only recorded at 15% of the point counts), so this was converted to a binary variable (flowers present or absent). Based on the effort required and poor results from this method, during 2018 a simplified flowering scoring system was used: a percentage (0 represented no plants flowering, while 100% represented all visible vegetation was flowering). The median vegetation height was estimated visually in cm.

In addition we consider the following veld condition indices: percentage bare soil; median vegetation height; percentage *Vachellia karoo* (hereon: acacia); time since rain in 4 categories (< 2 days; 2 – 7 days, 7 – 30 days, no recent) based on farmer reports or presence of mud, puddles and ephemeral water sources; and a 'green' score (ranked 1- 10 with percentage of shrubs green, together with percentage of grass or forbs as green, with 1 all brown and no leaves, to 10 being all green with most of the ground covered with grass or forbs). The use of the green score and vegetation height were only initiated during the spring survey, from 2 August 2017 onwards. Grazing pressure, and associated veld condition, was classed as either: good (natural); light grazing; heavy grazing; overgrazed (poor condition); mixed or not applicable. These were gauged depending on feeding sign on grass or bushes, vegetation on soil turrets (indicating erosion), or evidence of sheet erosion.

The presence of a variety of landscape features that might influence bird presence were recorded (road type, presence of livestock, alien vegetation, telephone poles, power infrastructure). For this report we consider the impact of the following variables on species richness: presence of water; presence of farmsteads or settlements; cultivated land; and infrastructure. As water presence was generally scarce, for the presence of water we consider any points that had dams, pans, streams or reservoirs present. Topographical position was classed as either: plains, slope, valley, ridge/hilltop, or mixed. In the case of slopes and hills, aspect as a compass bearing was recorded.

The following climatic variables were recorded using a hand-held anemometer: wind speed (m/s), temperature (C). Cloud cover was estimated as a percentage. Counting was abandoned with wind speeds of 6 or more.

During 2017, the presence and activity of major arthropod groups was recorded following a ranked score from 0 – 3, following (Lee and Barnard 2015): termites, harvester termites, ants, flies, honey bees, solitary bees, wasps, butterflies, grasshoppers, dragonflies, beetles, bugs, and spiders. After exploratory analysis at the end of 2017 with low presence scores, this information was not considered useful and thus was not recorded during 2018.

We consider two measures of species richness: at the point level and pentad level. At the point level, a basic index of bird species richness was calculated as the number of unique species detected within 150m of the observer during a point. This provided a measure of point count species richness. At the pentad level, total species richness was considered as the sum of all species recorded across a pentad and then corrected by dividing by the number of points conducted. These differ in that the first is a better index of alpha diversity, while the second better capture gamma diversity (change in diversity as a function of area covered).

Range and Area of Occupancy

The second Southern African Bird Atlas Project (SABAP2) is a citizen science project, initiated in July 2007, targeting birdwatchers across southern Africa. Birdwatchers submit lists to a database managed currently by the FitzPatrick Institute at the University of Cape Town. At the pentad level, reporting rate is given by dividing the number of lists in which a species occurs by the total number of lists submitted for that pentad. Reporting rate is a species-specific measure of relative abundance. A summary of the design and protocol of this project can be found in (Underhill 2016b). The SABAP2 spatial sampling unit is the "pentad", which covers five latitudinal minutes by five longitudinal minutes. By contrast, SABAP1 ran from 1987 to 1991 and utilized quarter degree grid cells (QDGCs) as sampling units, which contain nine pentads. Reporting rate for a QDGC for SABAP2 is the mean across the nine pentads.

Much of the information required to make informed conservation decisions based on Range, Population Size and Population Trend exists in the SABAP2 database (Lee et al. 2017a). These include Extent of Occupancy (EOO), which roughly equates to the sum of area covered by quarter degree grid cells (QDGCs); Area of Occupancy, which correlates well with the area covered by pentads; and trend, which can be measured either as population change between atlas periods, or by examining reporting rate trends on an annual basis from SABAP2 (2008 to present). Range and pentad area are presented in Table 1 for the Karoo endemic species.

Reporting rates and density estimates

This information in this section has been published in Lee et al. (2018), but a background, including the initial data analysis, are presented here for continuity. Population size can also theoretically be calculated by implementing detection covariates to reporting rates, but these likely need to be tailored to each species, or at least, by biome (Lee and Barnard 2017). On the ground calculation of density estimates are required to implement this.

We used Distance for R (Miller 2017) to find bird densities for the 49 most common species at the pentad level using point count data collected during the 2017 surveys. We fitted data for each species using a variety of detection functions and adjustments, some with wind or time period as early (count conducted prior to 9am) or late as covariates. Models with time in minutes since daybreak as continuous variable generally failed. Models tested included: hazard rate with no adjustments, half-normal with no adjustments, uniform, hazard rate and half normal with wind speed or time as covariates, hazard rate with cosine adjustments and polynomial adjustments, half normal with cosine or hermite polynomial adjustments. The best model by AIC and Cramer von-Mises values, which indicate goodness of fit, was selected for obtaining density and cluster estimates. For missing group size data we used mean group size. Distance for data for species with >100 encounters was truncated to include only those within the 75% quantile of the density distribution of distance bands, or truncated at 90% of maximum distance for species with >50 encounters. For species with <50 encounter, all data was used. Density estimates were saved as number of individuals per square kilometre. Density estimates were estimated for each pentad through stratification using the global detection function for comparison with reporting rates.

We downloaded species data at the pentad and year level from the SABAP2 public information website from the following URL code, where 583 is the unique species code for Karoo Scrub-robin in this example:
http://sabap2.adu.org.za/inc/species_data_download.php?spp=583&section=6#menu_left

Data was filtered to include only the years 2015 – 2017, for which 385 atlas cards were available. There were insufficient cards to analyse reporting rate for 2017 only (163) when applying a threshold of 4 or more cards. Reporting rate was calculated for this period as the number of cards with a species recorded divided by the total number of cards for each pentad. For comparison, regressions were also conducted using reporting rates for the entire SABAP2 period (2007-2017), but fits were generally worse, suggesting where possible for this type of analysis year by year reporting rates would be preferable.

To analyse the relationship between reporting rates and density estimates, we applied to each of the twenty most commonly encountered species in 2017 a binomial (logistic) regression generalised linear model (GLM). Only 2017 data was considered as this region had better atlasing coverage. The relationship between reporting rate and density was also explored at the community level, using mean scores of density and reporting rates from each species. Here, the set of mean reporting rates had a normal distribution, allowing linear modelling. A range of models using various transformations of data with mass as covariate were applied, with the best model selected by highest adjusted R squared value.

Karoo range specific density estimates

A density estimate is a function of abundance and area: a species might be very common, but not occur over a wide area. If density estimate calculations use a large area based on where a species is not found, then abundance could appear lower than it is where the species actually occurs. To account for this, we calculated range specific density estimates for the most commonly encountered species in the Karoo, using only the range of the Karoo in which the species was recorded during our surveys. To do this we first calculated for each of the 78 most common species a minimum convex polygon (MCP) based on the points where the species was encountered during the survey using the 'hull' function from the 'sf' package (Pebesma 2018) in R. We then selected all the points falling within the MCP from which to calculate density estimates. Density estimates were then calculated as per the methods described above (i.e. selecting the best model from a variety of detection functions and covariates). Then, a population estimate was calculated as the lower and upper density estimates multiplied by the area of the MCP.

For regional density estimates used to calculate within range population estimates, we used Year as the stratification variable. This was because count conditions were different between years, with 2017 coinciding with the end of a prolonged drought period, whereas some regions surveyed during 2018 had experienced good rain and thus very different veld conditions.

Statistical analysis – patterns and environmental predictors of species richness

We examined patterns of total species richness at the pentad level for the spring surveys, using log of total species counts by pentad as the dependent variables, corrected for effort. This metric was chosen as the dependent as the resulting distribution was Gaussian, and prior model exploration with poisson distribution resulted in poor fits, probably as standard deviation was less than the mean for the total numbers of observed species observed (36 ± 11 per pentad). This analysis covered 128 of the 150 pentads and 2462 point counts. This subset was necessary also to account for seasonal influence (including only counts from the spring periods of each year). Linear modelling was conducted for most environmental variables to identify strongly correlated variables. Relationships were considered significant at the $p = 0.05$ level.

We first explored spatial patterns by investigating the impact of longitude and latitude, to account for likely spatial autocorrelation. Similarly, we examined the temporal influence of total species richness by modelling the effect of year. From these, both longitude and year were identified as significant variables, and thus included as random effects in the following model (below), with longitude as slope and Year as intercept.

Then, to identify the most important environmental covariates associated with total species richness from a set of least correlated variables we ran the following model; and then found the best model by AIC using the step function from the lmerTest package (Kuznetsova et al. 2017). We present alternative models, dropping correlated variables.

Log(Species count in a pentad / effort) ~ Sand_cover + Tree_cover + Sheep + Cattle + Green_score + Veg_height + Acacia_cover + Year + Grass_cover + Altitude

A similar Karoo endemic species richness analysis was run. Here the dependent variable was the number of Karoo endemic species encountered (of the 10 Karoo endemic species as well as Cape Long-billed Lark and Karoo Chat) in a pentad.

To examine landscape, land-use and point features influencing species richness at the point count level (number of species recorded during a 10 minute count), generalised linear models using the poisson distribution were implemented. As there were many possible covariates, several model exploration strategies were used. Where possible (if models converged), the lmerTest package (Kuznetsova et al. 2017) was used to explore variables using pentad and Year as random effects. To identify the most important variables, the following model was created, and then the best models identified, together with the top model with explanatory power of variance according to adjusted R squared using the dredge function from the MuMIn package (Barton 2011).

Species richness at a point ~ factor(Water presence) + factor(Farmhouse presence) + Rain_score + Altitude + Dirt_Road + Tar_Road + Green_score + Topography(valley, slope, ridge etc) + Wind + Latitude + Longitude.

We also conducted a similar analysis to the above for the 100 most common species (plus Sclater's Lark) in order to identify predictor variables of presence in relation to predictor variables explaining presence. We fitted the following logistic regression model and then selected the best model using the stats::step function.

Bird presence/absence ~ Veg height; Green score; presence of farmhouse, tar road, water, sheep, flowers, or telephone poles, Prosopis; Veld condition; percentage cover of Sand, Grass, Acacia, or other tree cover; topography; time since rain (recent <7 days) or longer); as well as confounding variables wind, temperature, and pentad.

Data was filtered to include only birds detected within 150m of the point count. We filter the results to present a list of species likely vulnerable to contaminated waste ponds likely to be a feature of the landscape under shale gas exploration. Results are in Appendix 2.

Spatial distribution modelling of key Karoo endemic species

Currently, SABAP2 summary maps for many Karoo species are either: not useful, due to the poor atlasing coverage over most of the Karoo region and hence local abundance and ranges are poorly defined; or genuinely misleading, especially in the case of mistaken identity, which is a high likelihood for most of the Karoo 'LBJ' species; or a combination. For species that were split between SABAP1 and SABAP2, some range maps have so many errors as to be near useless: the case of the Long-billed Lark complex is an excruciating and obvious example of this (Figure 3), although for Karoo Lark errors are a lot more subtle (Figure 4).

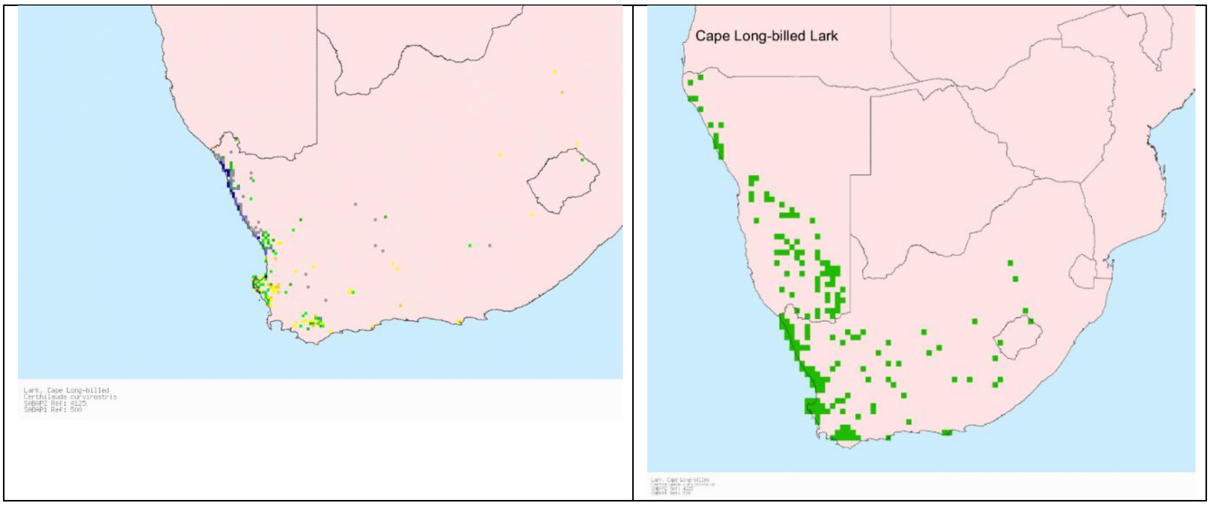


Figure 3: According to this SABAP2 pentad range map (left), Cape Long-billed Lark, a strandveld endemic, occurs in the Overberg (where confusion occurs with Agulhas Long-billed Lark), while a smattering of highly unlikely records occurs across the country, including Lesotho. The 'derived distribution' map (right) is extraordinarily inaccurate (downloaded on 11 January 2019 from http://sabap2.adu.org.za/species_info.php?spp=4125&section=4#menu_left).

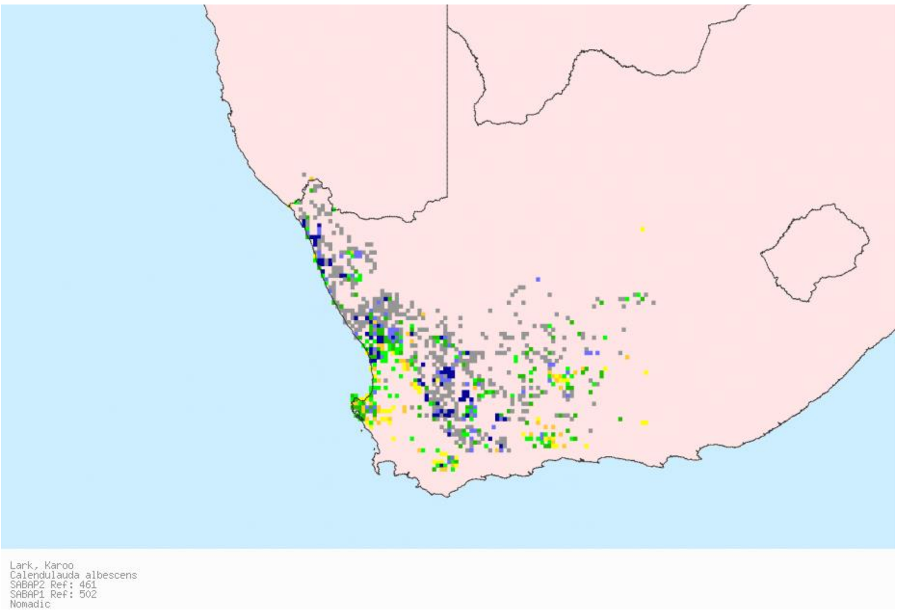


Figure 4: SABAP2 distribution map for Karoo Lark at the pentad level: blue indicates high reporting rate and yellow low reporting rate, with grey records incidental or low coverage pentads. Here, the range is poorly defined, with an unexplained gap over Namaqualand, and multiple errors: notably the Overberg (species does not occur here), eastern Klein Karoo and Aberdeen plain regions (species almost certainly does not occur here). Experienced birders (e.g. Mel Tripp, Wim de Klerk, Brian van der Walt) have not recorded the species in the Overberg. According to local expert, Wim de Klerk, Karoo Lark records of the Overberg likely represent juvenile Red-capped Lark.

It was thus of great interest to create range maps independent of SABAP2 presence data. For this I made use of 2 methods: a logistic regression GLM; and a random forest machine learning method using the 'ranger' package (Wright and Ziegler 2015). For GLM modelling, it is recommended that uncorrelated predictor variables are used. We thus use the 19 WorldClim variables and tested these for correlation across South Africa. Many of the variables were highly correlated, and we selected the following which are a balance of temperature and rainfall. We also derive a variable to indicate where the balance of rain falls in winter, since this is an important variable defining the Succulent Karoo

Biome. The 6 variables used are indicated in Figure 5 below. For the random forest method, we make use of all 19 variables and include latitude and longitude as further predictor variables.

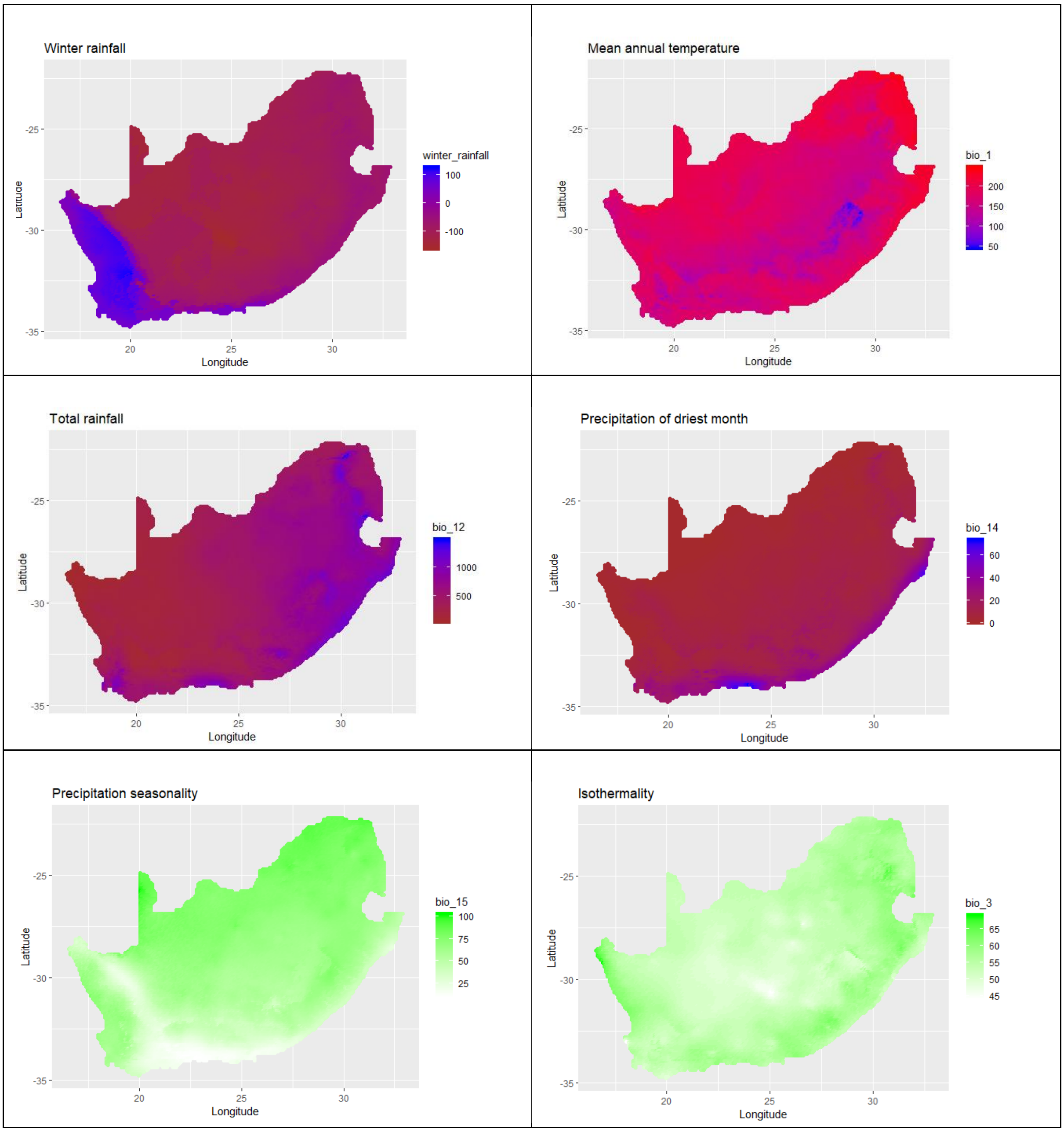


Figure 5: Worldclim variables used to predict species presence across South Africa

To project the range across South Africa, we used an additional 2 sources of data. Firstly, point counts conducted in a similar method across the Fynbos (which present both absence data and a few additional presence records for some species)(Lee et al. 2015); and secondly, we use the SABAP data set for each species and extract pentads with a high confidence of absence (>20 reporting lists and 0 reporting rate). The locations of background points for modelling are indicated below (Figure 6).

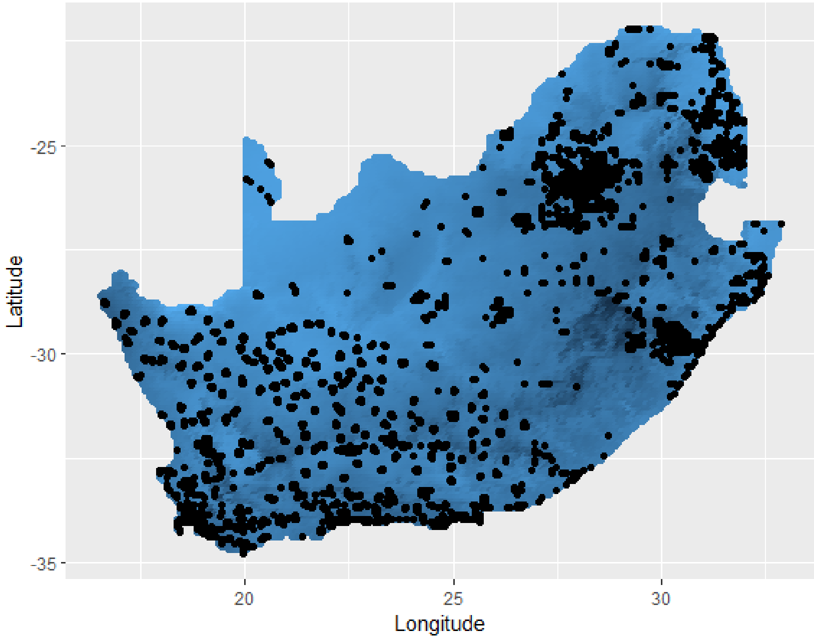


Figure 6: Points used to predict species presence either from point count surveys from Karoo and Fynbos, or from SABAP2 pentads with high confidence of absence (>20 pentads with species absent).

Results

Overall patterns of species richness at the pentad level across the Karoo study region

We recorded 16,232 encounters with groups of birds of 257 species over the study period. The highest species tally from point counts was recorded in pentad 3225_2540, with 66 species, with the lowest tally being 8 for pentad 3035_2250. The most frequently recorded species in terms of groups registered was Lark-like Bunting (1205 groups, Figure 7). The second most commonly recorded species, with 550 group encounters was the Rufous-eared Warbler (see below). Of the 257 species, 31 species (12%) were only recorded on 1 occasion: the full list of species with number encounters, mean and maximum group sizes are in Appendix 1.

Lark-like Bunting

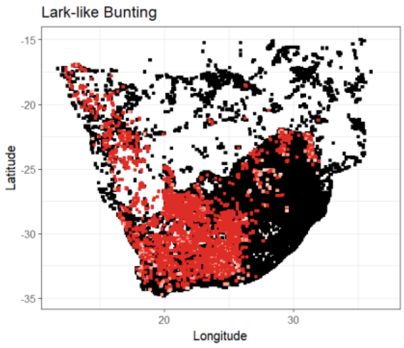


Figure 7: The most common bird in the Karoo, the Lark-like Bunting, with SABAP2 distribution map (but see below for dynamic versions of this map).

Longitude was a strong predictor of total pentad species richness when considered together with latitude, with pentads gaining about 1 species for each degree of longitude east (Figure 8). Patterns of species richness differed by year, with the west to east gradient most notable for the 2017 surveys (southern Karoo).

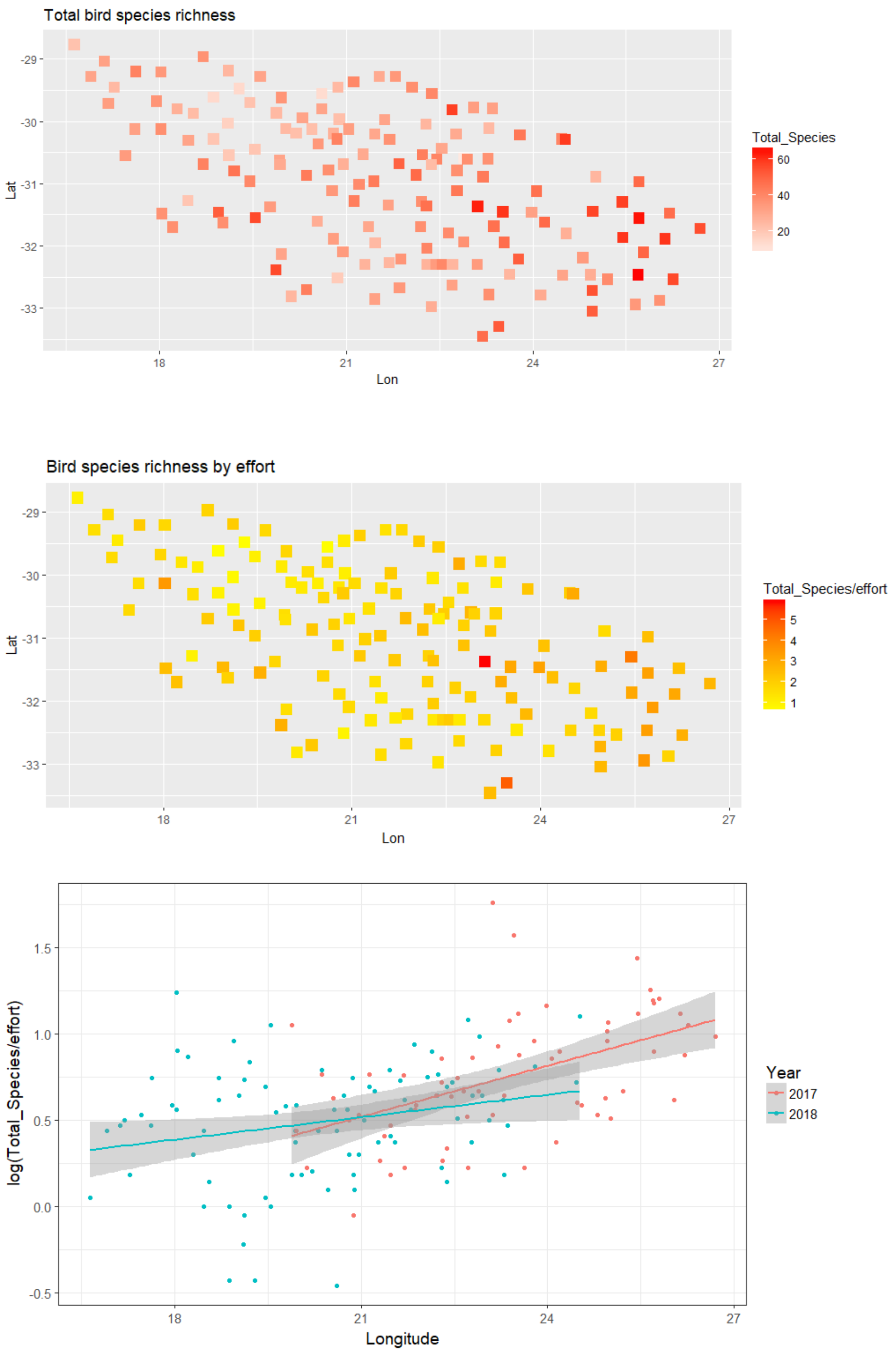


Figure 8: Spatial patterns of species richness across the Karoo. The top chart showing total species richness (uncorrected for any variation in effort) per pentad, while the middle chart corrects for effort (i.e. number of point counts conducted). The lower chart indicates the slope of the trend: pentad species richness increases by about 1 species for each degree of longitude east, but this trend is more noticeable for the southern Karoo (south of -31.5, or for surveys conducted during 2017).

Somewhat surprisingly given drought conditions of 2017, pentads surveyed during 2018 had significantly lower total pentad species richness: pentads surveyed in the south in 2017 had on average 1 species more (Figure 9). This result was surprising as the 2017 counting period was very dry: only 15% of point counts were conducted within a week of a rainfall event. During 2017 anecdotal reports suggested that winter rainfall was below average, resulting in a poor floral display over the spring time: 85% of counts were conducted at points where no flowering activity was recorded. However, the southern Karoo juxtaposes with the Fynbos and Albany thicket biomes, which may contribute non-Karoo species to the total species counts.

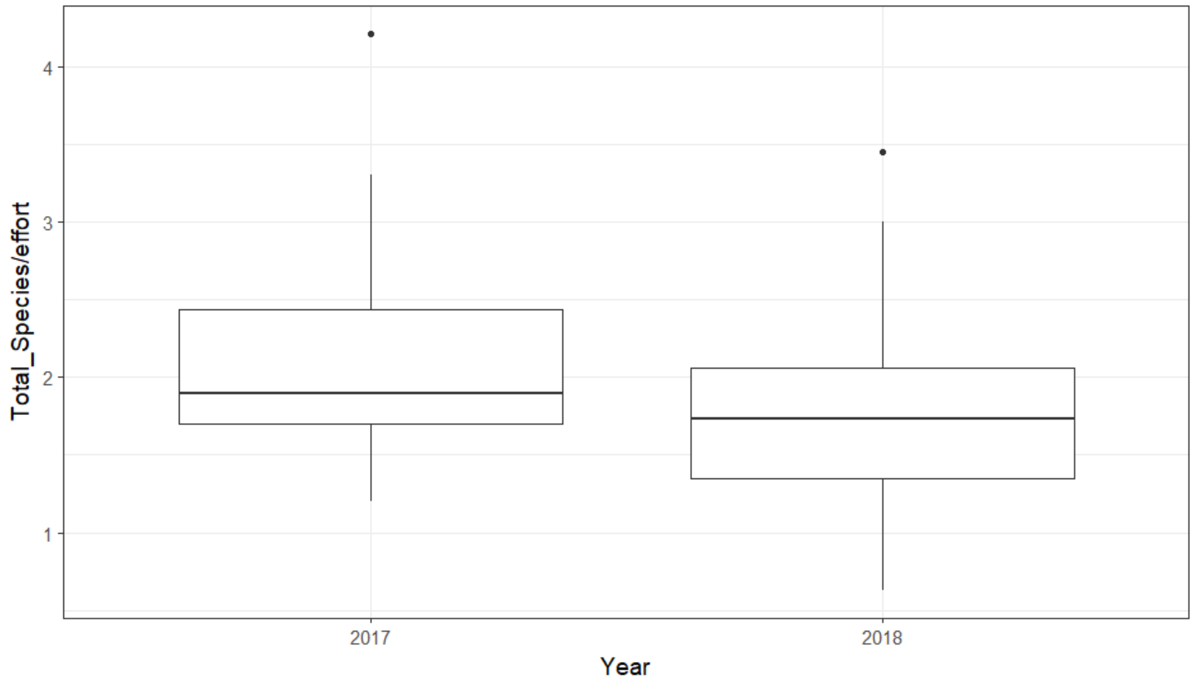
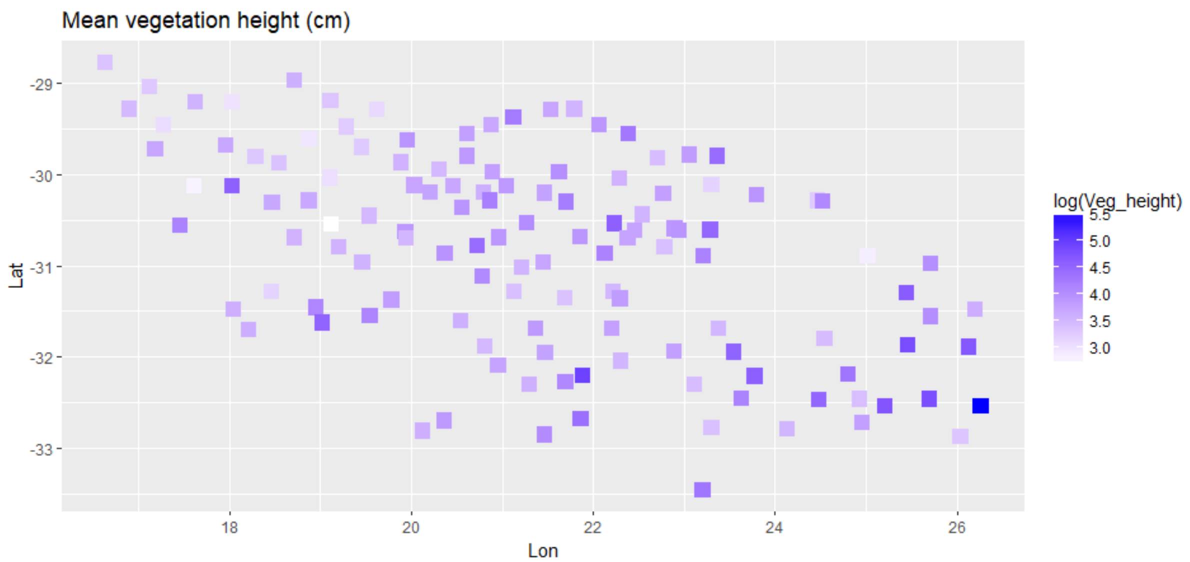


Figure 9: Pentad species richness was lower by about 1 species on average during the 2018 survey. Whether this was a consequence of time, local conditions, the juxtaposition of other adjacent biomes, or other reasons is not immediately clear.

Environmental predictors of species richness at the pentad level across the Karoo

Accounting for longitude and year of survey, the model selection process identified mean vegetation height and percentage sand cover in a pentad as the best predictors of species richness in a pentad, with a positive influence of increasing vegetation height (Figure 10), and a negative influence of increasing sand cover (Figure 11). The best model also included percentage grass cover and percentage acacia cover. However, these variables were correlated with the best predictor variables (grass cover is negatively correlated with percentage sand cover, while acacia cover is positively correlated with vegetation height). By contrast, the following variables did not explain pentad species richness when considering longitude, sand cover and vegetation height: altitude, other tree cover, sheep, cattle, or green score.



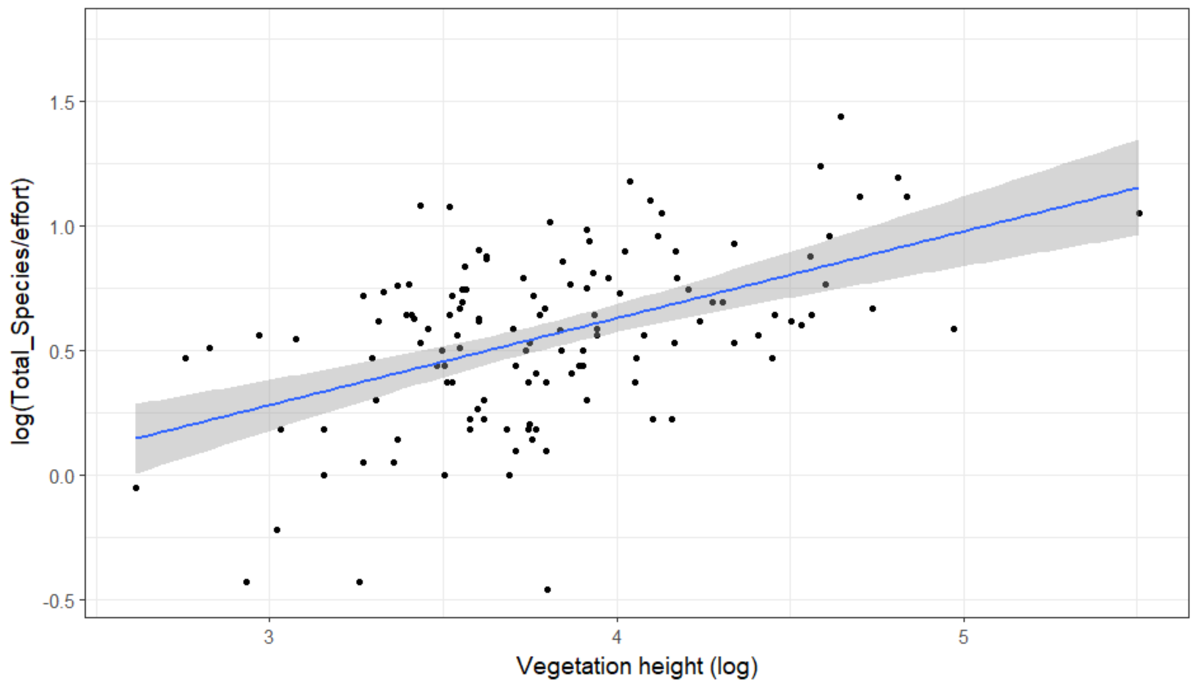


Figure 10: Mean vegetation height increases from the northwest to the southeast (top). Vegetation height ranged from a mean of 16 cm to 246 cm, with species richness increasing with vegetation height (the log transformation in the axis legends was applied to clarify the spatial trend).

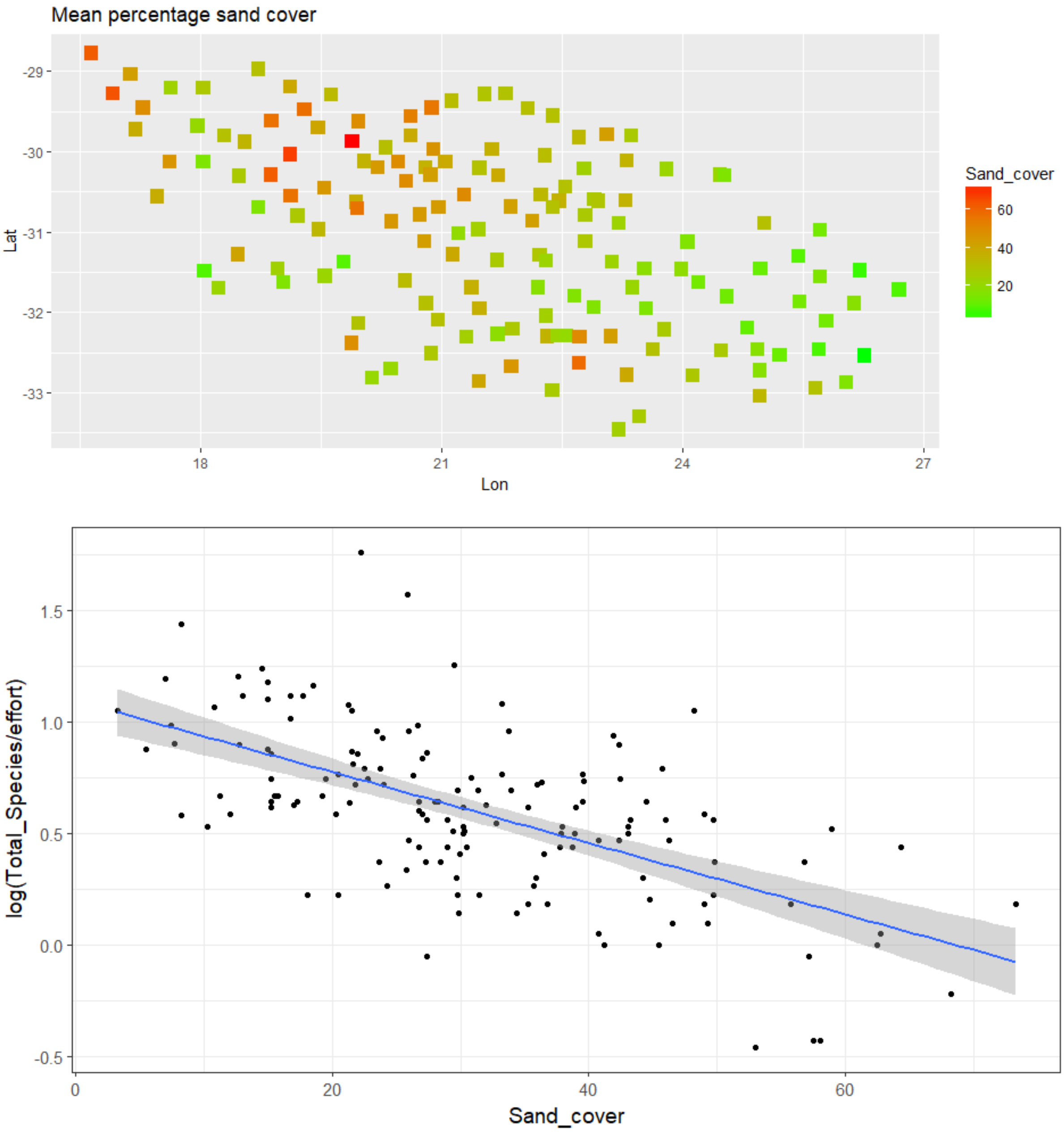


Figure 11: Sand cover increased from east to west (i.e. increasing vegetation cover from west to east, top figure), and was negatively correlated with species richness (bottom figure).

Overall patterns of Karoo endemic species richness

Overall Karoo endemics species richness showed a contrasting trend to that of overall species richness: Karoo endemic species richness was highest in the west, declining eastwards, with the loss of approximately one species for every 2 degrees of longitude (-0.56 ± 0.06, $t = -8.79$, $p < 0.001$; Figure 12), and similarly from north to south (-0.55 ± 0.13, $t = -4.17$, $p < 0.001$). Overall Karoo endemic species richness was negatively correlated with grass cover (-0.12 ± 0.05, $t = -2.6$, $p = 0.01$, Figure 13) and acacia cover (-0.10 ± 0.05, $t = -2.18$, $p = 0.03$, Figure 14), but also weakly positively correlated with altitude (0.11 ± 0.05, $t = 2.20$, $p = 0.03$, Figure 15). The effects of the environmental variables considered here were not as strong compared to those identified for total species richness. See Figure 12 for distribution of encounters with groups of endemic bird species plus Large-billed Lark, Cape Long-billed Lark and Karoo Chat. Green Score and other tree cover were not significant predictor variables of Karoo endemic bird species richness (spatial patterns are illustrated in Figure 16). Likewise, presence of cattle and sheep were not correlated to endemic bird presence (spatial patterns illustrated in Figure 17). Individual species distribution patterns differed depending on species (Figure 18).

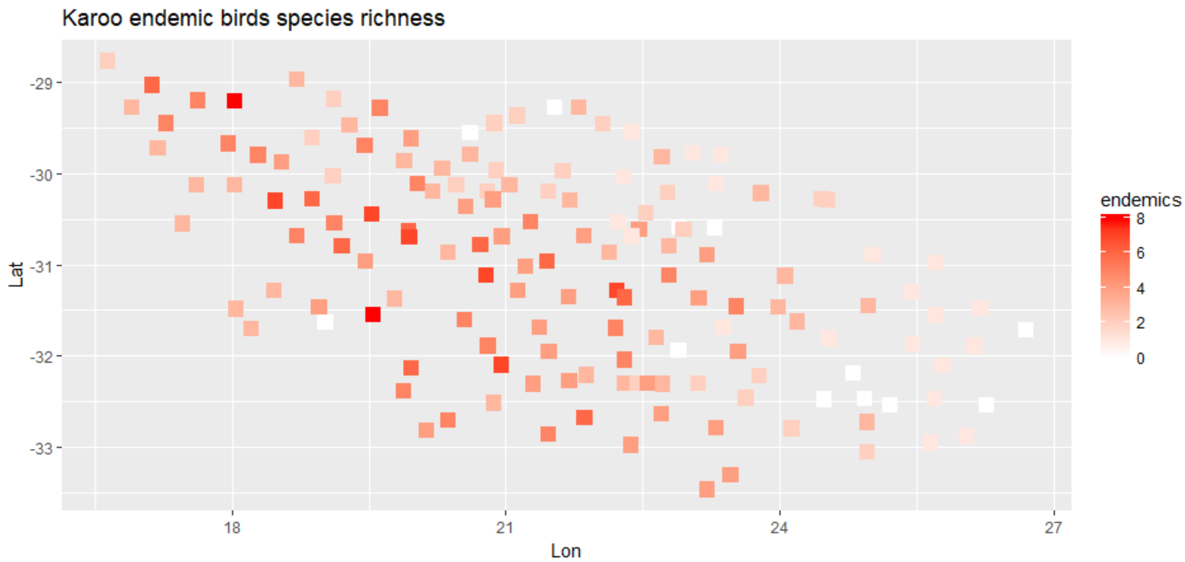


Figure 12: Here the number of the total possible set of 13 species is indicated. Overall Karoo endemic bird species richness declined from a high in the west to almost none in the east. Endemic species richness was negatively correlated with increasing grass and acacia tree cover.

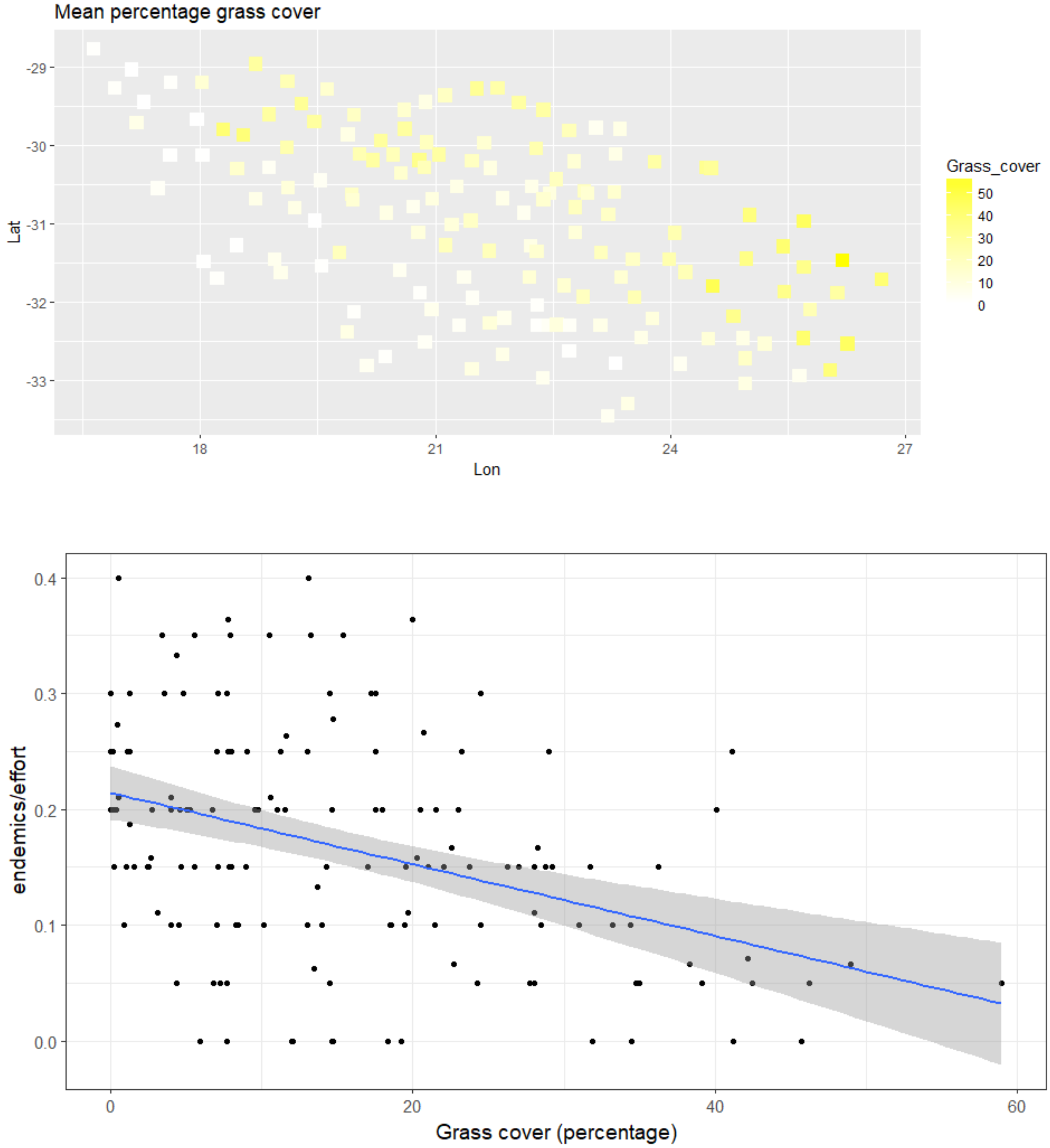
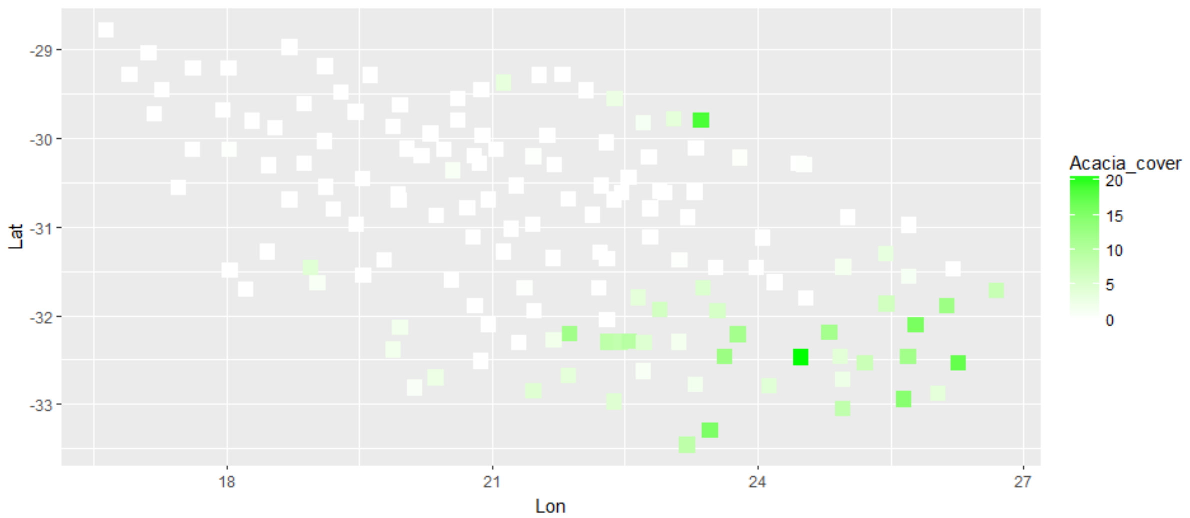


Figure 13. Top: the spatial pattern of mean percentage grass cover, with cover increasing north-eastwards. Bottom: the number of endemic birds encountered decreased with increasing grass cover.



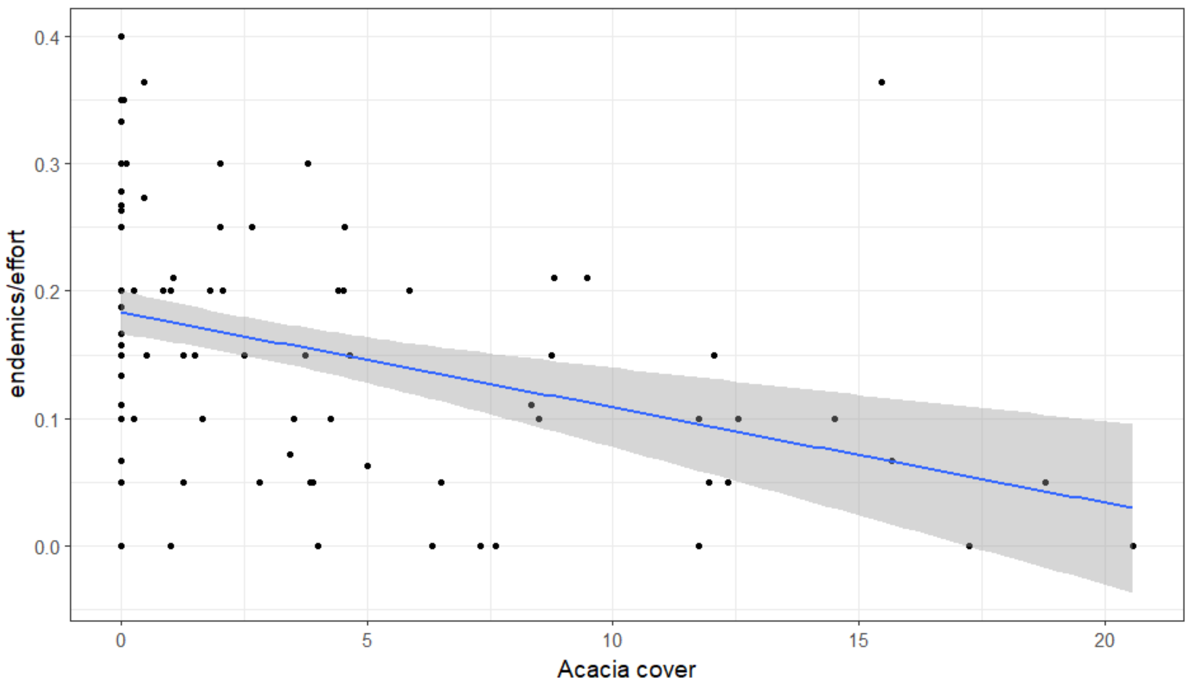


Figure 14. Top: the spatial pattern of mean percentage acacia cover, with cover mostly absent, but increasing south-eastwards. Bottom: the number of endemic birds encountered decreased with increasing percentage of acacia cover.

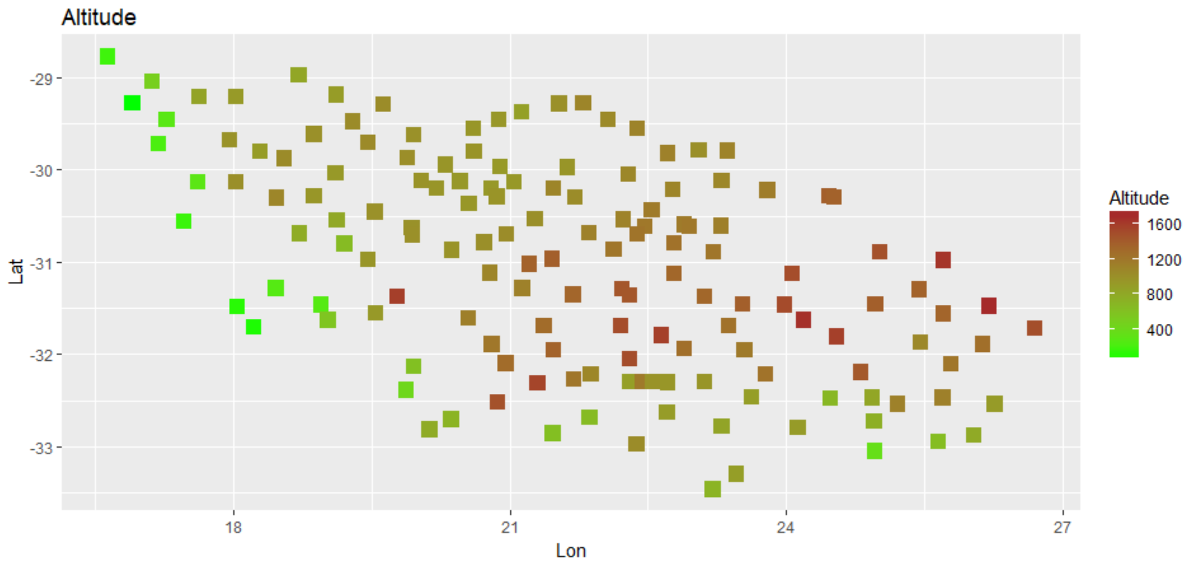
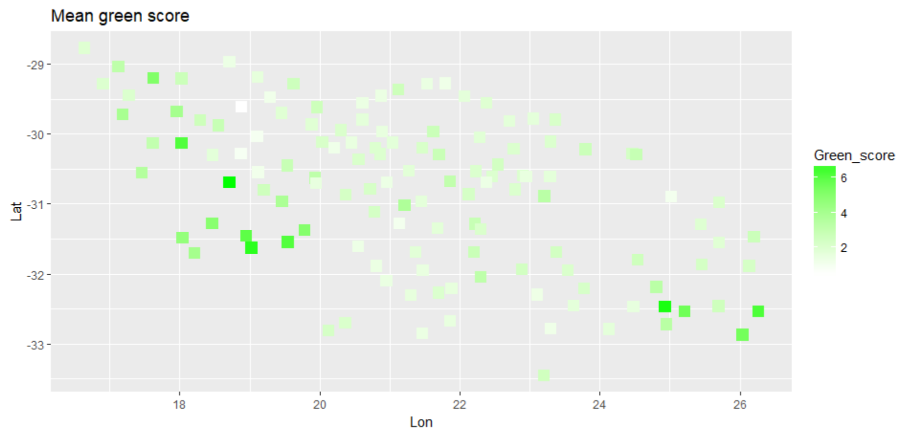


Figure 15: While altitude in isolation is a poor predictor of endemic birds species richness, it was included as a non-significant positive predictor if considered in conjunction with grass and acacia cover.



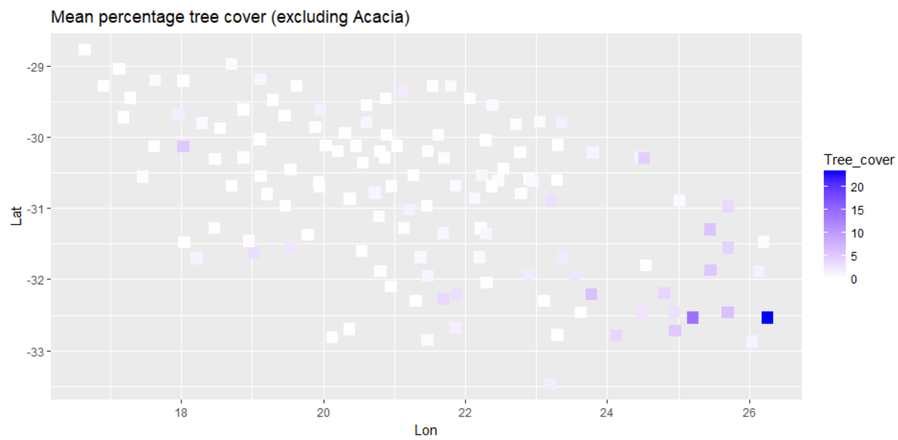
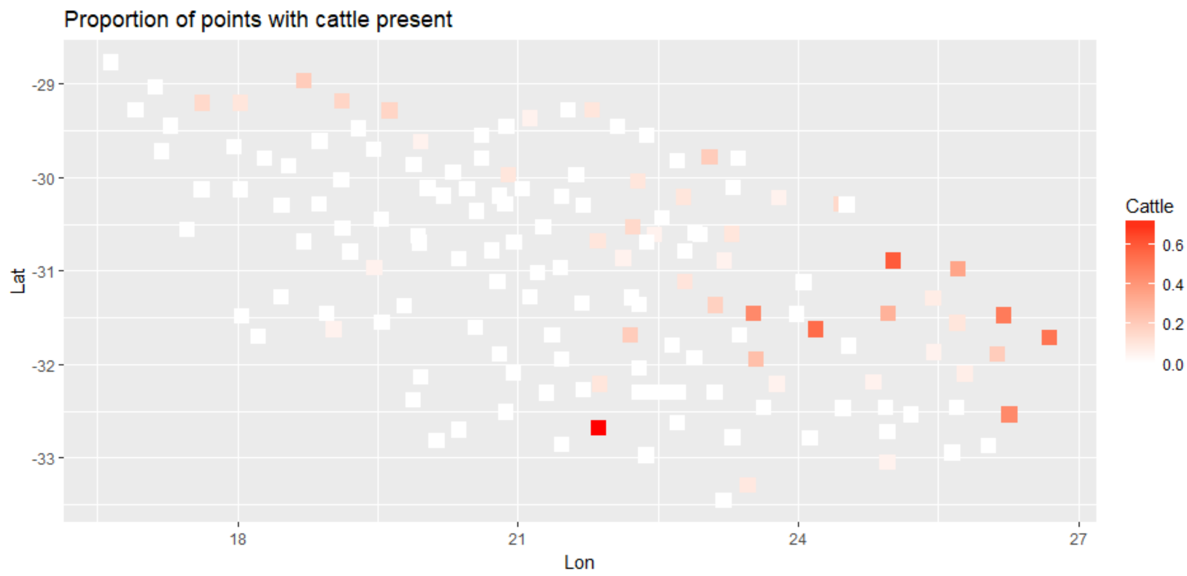


Figure 16: Spatial patterns for green score and percentage tree cover (excluding acacia). Neither of these were considered important for predicting either total species richness or endemic species richness.



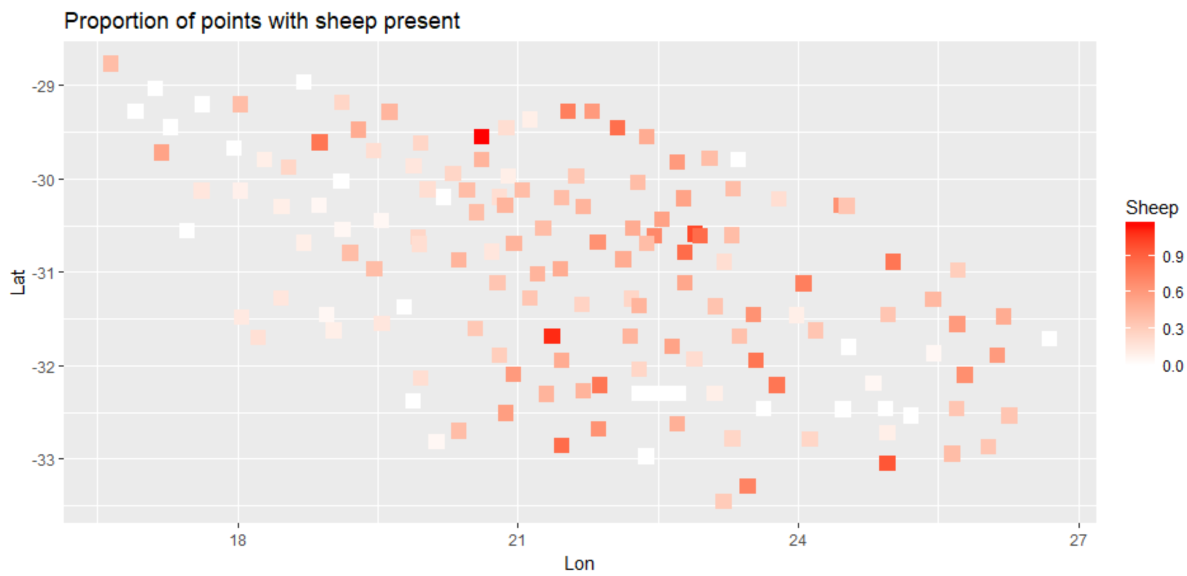


Figure 17: Despite concerns about the impact of livestock on vegetation and thus bird species diversity, there was no correlation between either of these variables in relation to total species richness, and neither variable was retained in the model predicting Karoo endemic species richness. Cattle presence increased from west to east, while there was no spatial pattern evident for sheep stocking.

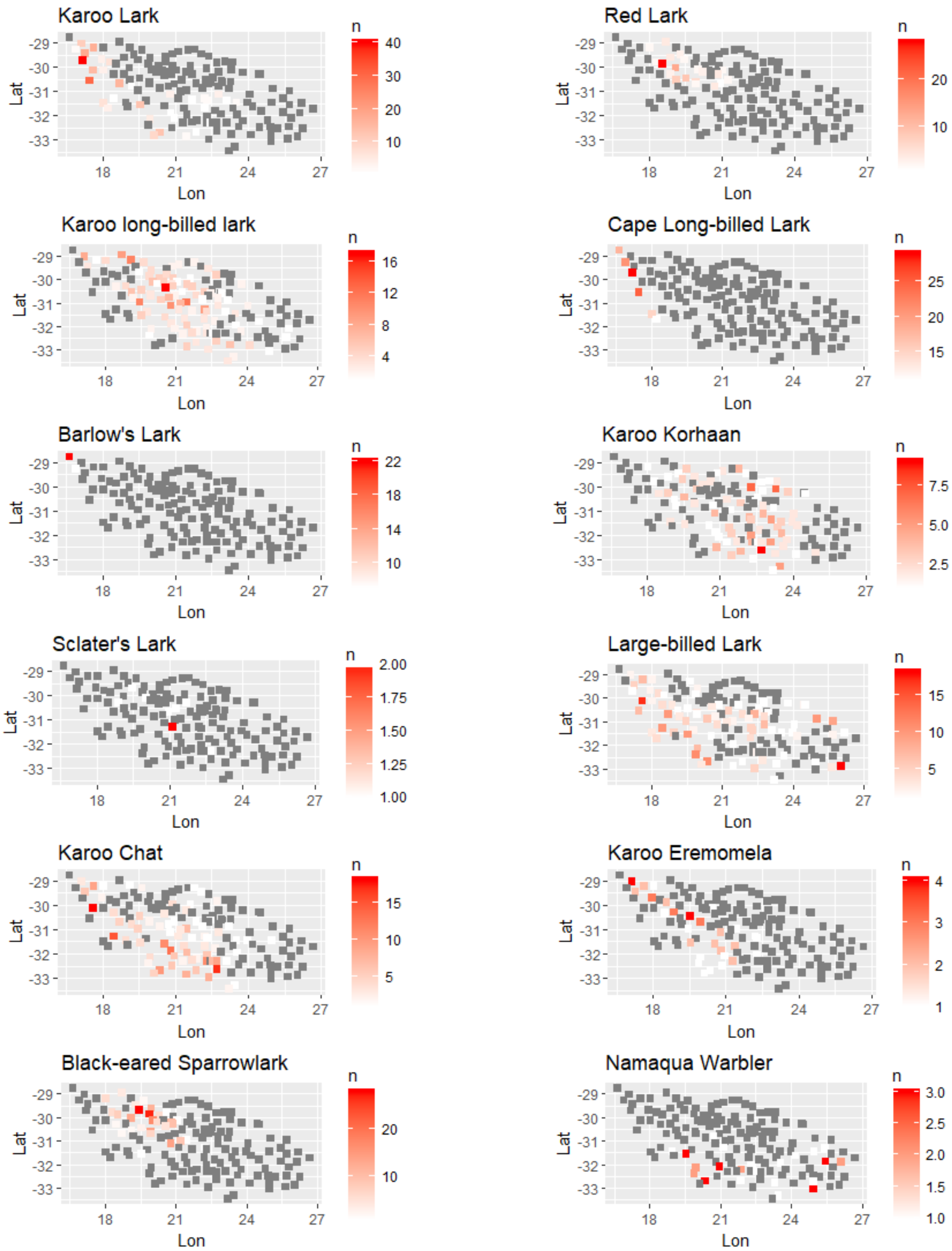


Figure 18: Numbers of group encounters (n) during point counts with 10 endemic Karoo bird species (plus Karoo Chat and Large-billed Lark). Grey indicates pentads with no encounters.

Effects of space and time on patterns on bird abundance

Variation in the numbers of birds detected within 150m of the observer varied massively between points (mean ± sd = 8.8 ± 99, range 0 to 328). Spatial patterns of abundance followed those of species richness (these metrics were correlated (Pearson's product moment correlation = 0.61, $t = 9.3$, $p < 0.01$, $df = 148$)), increasing slightly eastwards with a gain of about 1 bird per point per degree of longitude. Highest abundance was recorded near Victoria West due to the presence of the large Lesser Kestrel roost in this pentad, combined with dam and town presence. It should be noted these are abundance measures not corrected for by detection.

Abundance was most strongly explained by increasing grass cover, decreasing sand cover, in conjunction with altitude, where abundance declined weakly. Due to the variation, a log transformation was required to obtain a gaussian distribution suitable for modelling. However, as patterns are similar to those found for species richness, we don't explore this metric further here.

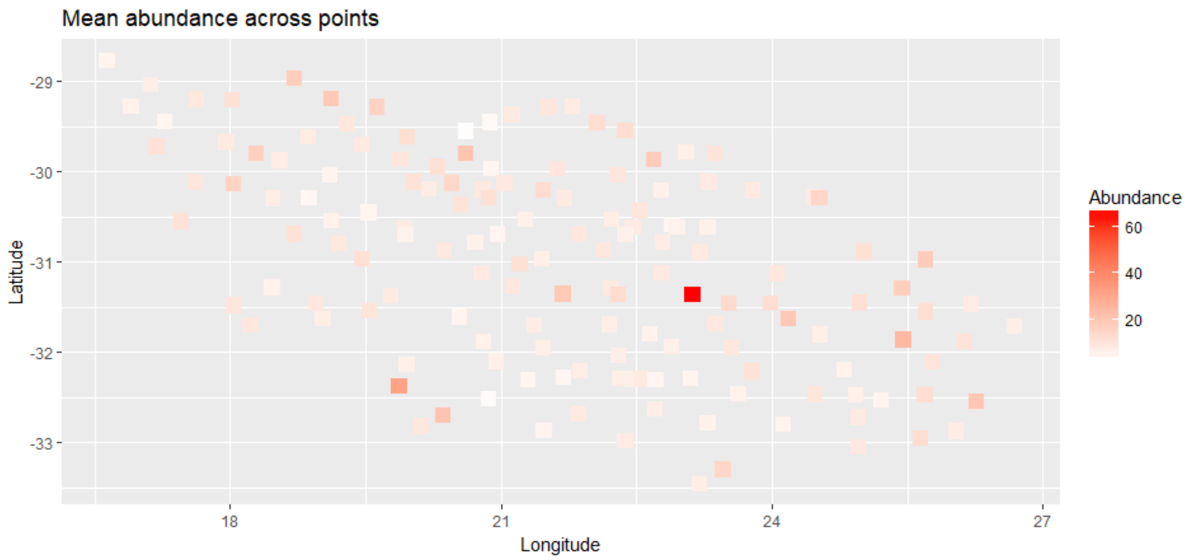


Figure 19: Spatial patterns of abundance (total of all birds seen at a point) across the Karoo pentads surveyed, as illustrated here by mean bird abundance across the points in a pentad.

Variables associated with higher species richness at a point count

The following variables were retained in the best model explaining species richness of a point count: presence of water, presence of farmhouse, time since rain, wind strength, tar road, and topography. In terms of explanatory power of species richness, the presence of water was the best predictor (R^2 = 0.3). The patterns associated with these predictor variables are illustrated in the following set of figures (20 – 25). Wind had an influence on probability of detection and as such is retained in models when examining individual covariate effects.

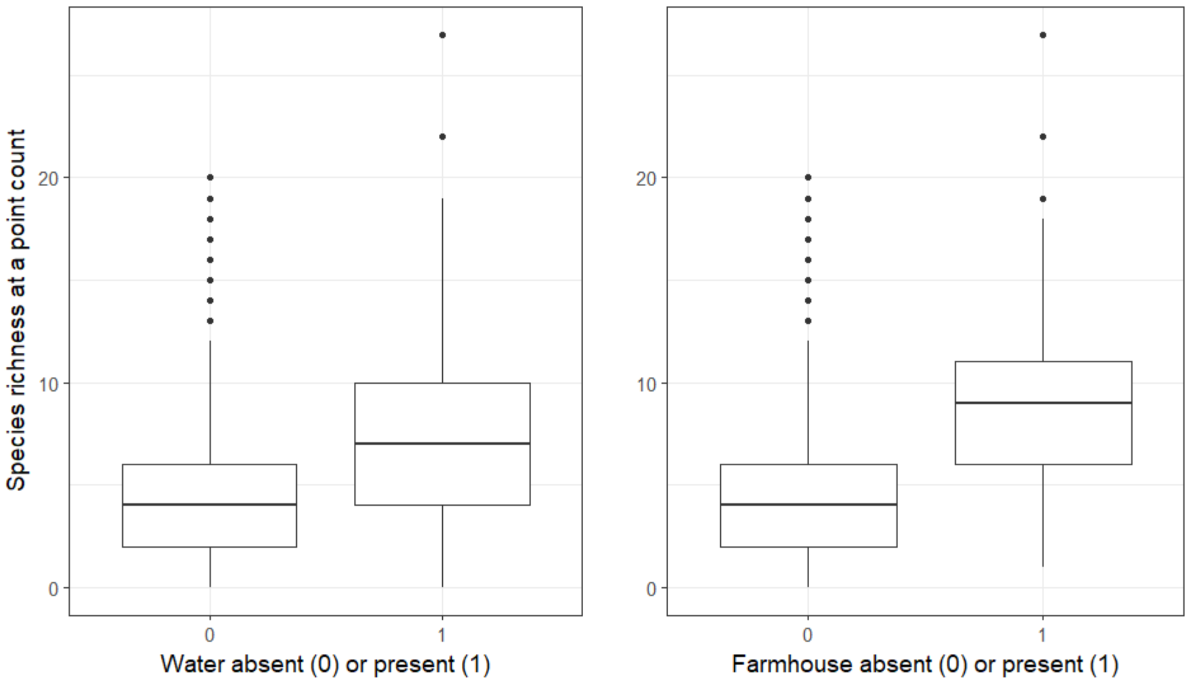


Figure 20: The presence of water, usually as windmills with reservoirs and drinking troughs, dramatically increased the number of species recorded at a point count (with water: 7.32 ± 4.51 species; without water: 4.02 ± 2.89). Farmhouses were often associated with water, as well as with pasture and increased vegetation cover, all of which in turn were associated with increased species richness. As such twice as many species were recorded at points conducted near farmhouses (with farmhouse: 9.11 ± 4.52 species; without farmhouse: 4.16 ± 3.04). However, farmhouses were generally rare in the overall landscape.

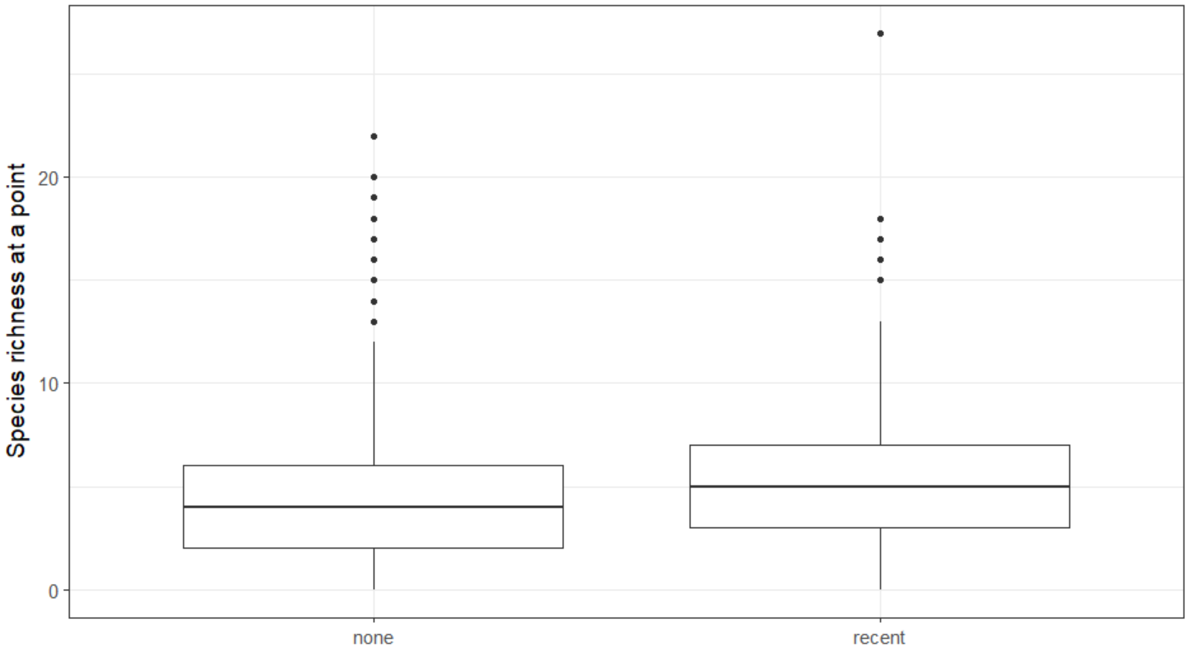


Figure 21: Species richness was significantly higher where points were conducted within a week of a rainfall event, even when controlling for wind and longitude and keeping pentad as a random effect (mean species richness at points with rain within 7 days: 4.95 ± 3.37, otherwise: 4.21 ± 3.16). There were six species which were more frequently encountered after recent rain (see next section).

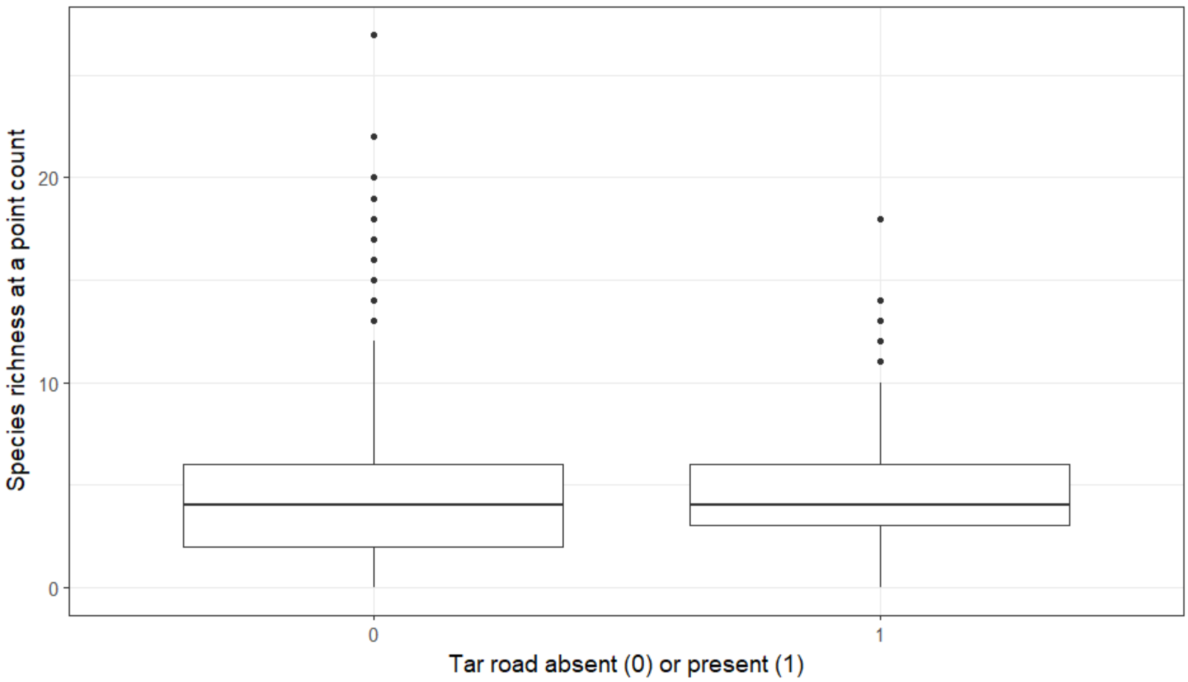


Figure 22: Point counts were conducted along tar (paved) roads on 152 counts (5.3% of all counts), but had no influence on species richness overall. Species richness at points along tar roads was slightly lower compared to other points (mean species richness at points along a tar road: 4.71 ± 3.13, otherwise: 4.27 ± 3.19; t = -0.874, p = 0.382, controlling for wind and pentad as random effect).

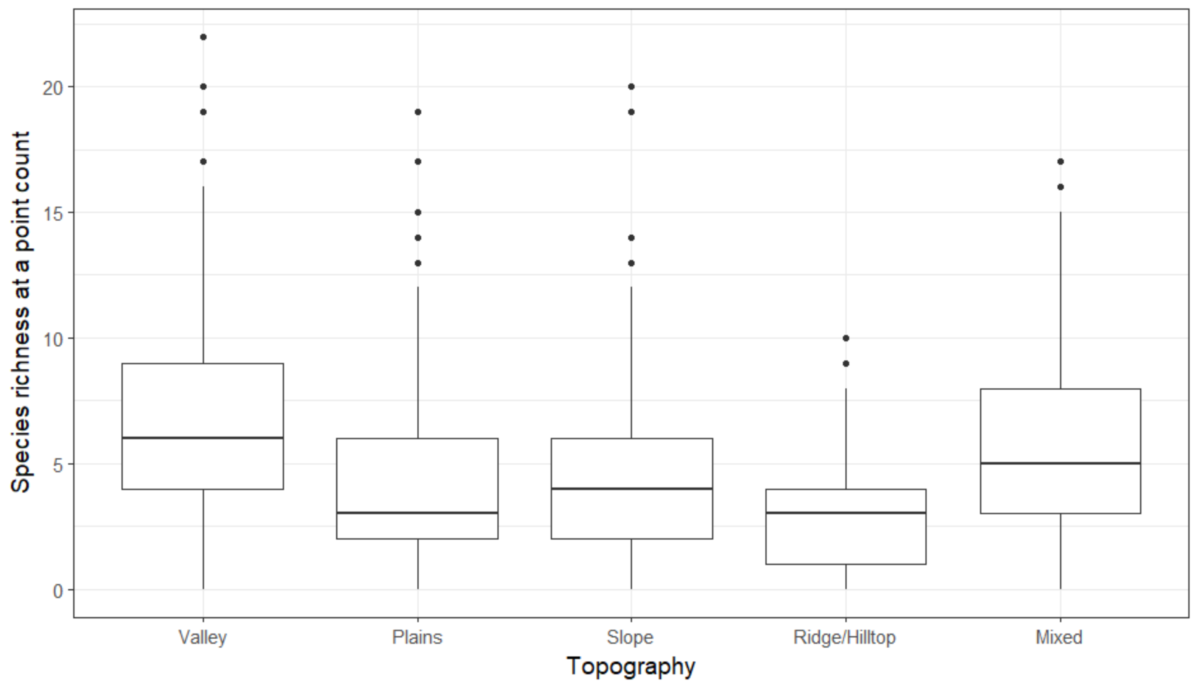


Figure 23: The topographical position in the landscape played an important role in determining species richness at point: highest in valleys and lowest on ridges or hilltops. Topographically mixed locations had a wide range of associated species richness.

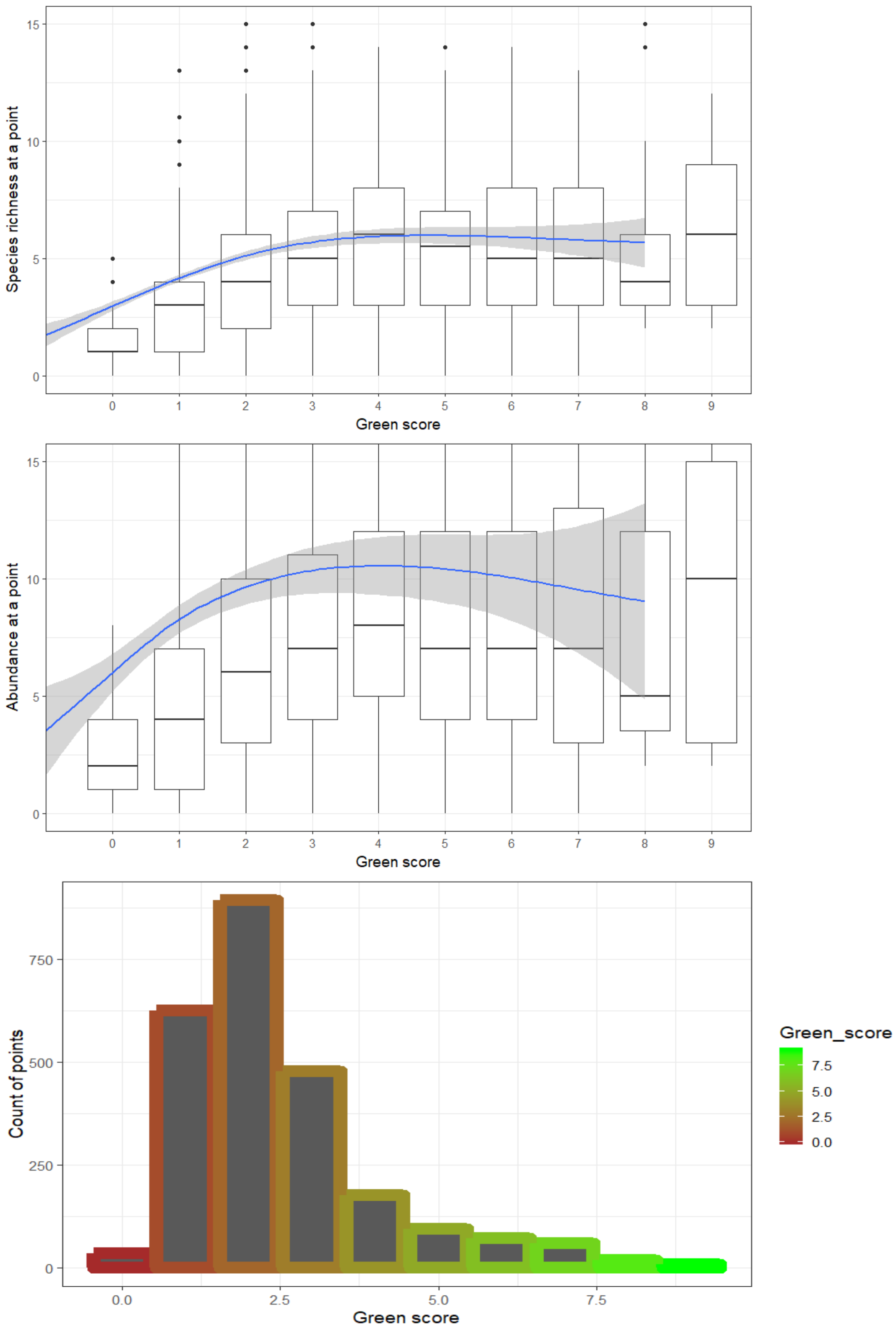


Figure 24: The relationship between species richness of a point and the green score assigned to the vegetation where 0 = all dead, 1 = 10% of plants green etc. Species richness and number of birds observed at a point were low for low green scores, but stable after a certain point. Overall, green scores were low – only 6.7% of points had scores of 5 or over (histogram of distribution of scores indicated in the lowest chart).

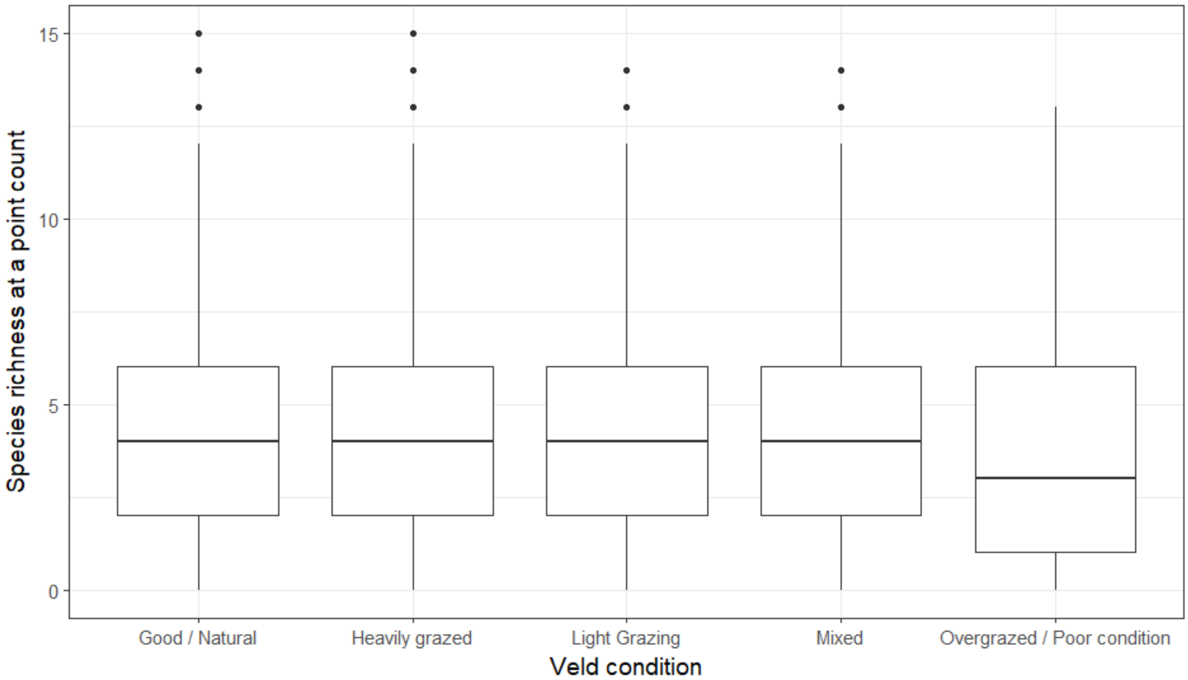


Figure 25: Species richness was lowest for points classed as overgrazed or poor condition (poisson glm coefficients with wind as covariate: good = 1.75 ± 0.06, overgrazed = -0.21 ± 0.06). A similar pattern was observed for bird abundance.

Best predictor variables for predicting individual species presence

We ran models using a variety of landscape features to predict species presence or absence. From this we present species most associated with water in Appendix 2. Full model results for the endemic birds are presented in Appendix 3.

The importance of predictors across the set of 101 birds for which this was tested is seen in Figure 26 below. Overall, the percentage sand cover was the best predictor of species presence, retained at the $P < 0.01$ level for 26 species, but with contrasting effects: negative for 17 species e.g. Rock Kestrel and Neddicky, but positive for 9 species: Stark's Lark, Black-eared and Grey-backed Sparrow-lark, Red Lark, Tractrac Chat, Cape Long-billed Lark, Barlow's Lark and Common Quail.

Sand cover was followed by the Green score in terms of importance, again mostly positive for 23/26 species. The presence of water had an overwhelming positive influence on species presence (Appendix 2). This was similarly the case for the presence of a farmhouse. The displayed topographical positions (plain, ridge, slope) were mostly registered as negative compared to valley, which was the model intercept in most cases. Grass cover also showed balanced positive and negative effects for the 20 species where this was considered important, mainly negative for Karoo endemics with the exception of Black-eared Sparrowlark and Red Lark. Other species associated with increasing grass cover were Eastern Clapper Lark, Northern Black Korhaan, Ant-eating Chat, Scaly-feathered Finch, Long-billed and African Pipit, Stark's Lark and Grey-backed Sparrowlark.

Of the 18 species for which percentage acacia cover was a significant predictor of presence, this was mostly positive (16/18), with only Layard's Titbabbler and Yellow-bellied Eremomela negatively correlated with increasing acacia cover. Interestingly, no species was negatively correlated with the presence of *Prosopis*. The presence of this species was used as a presence / absence variable, as only a few locations were associated with very high infestation. Never-the-less, 16 species were positively associated with the presence of this alien invasive tree, with strong associations for Chestnut-vented

Titbabbler, Pririt Batis, Southern Masked Weaver and Red-headed Finch. These were also species generally present with increasing vegetation height, while by contrast the following species were negatively associated with increasing vegetation height: Capped Wheatear, Red-capped Lark, Rufous-eared Warbler, Stark's Lark, Sickle-winged and Karoo Chat. Related to that, Red-eyed Bulbul, Red-faced Mousebird, Glossy Starling and Bar-throated Apalis were all positively associated with increased 'other tree' cover (i.e. not acacia or *Prosopis*).

Several nomadic species were associated with flower presence, including Yellow Canary, Stark's Lark, Black-eared Sparrowlark, and Common Quail, as well as Southern Double-collared Sunbird. Of the species associated with recent rain, this may rather be as a result of increased detections due to activity and vocalisations for some species after rain, especially in the case of species considered resident such as Cape Long-billed Lark and Namaqua Warbler. Southern Double-Collared Sunbird was particularly strongly associated with recent rain.

Of the veld condition factors, association was mostly negative for veld of poor conditon, especially for Cape Long-billed Lark, Southern Double-Collared Sunbird and Cape Clapper Lark. A noteable exception was Chestnut-vented Titbabbler, which was associated with veld condition of poor condition.

Several species were positively associated with telephone poles: Cape Crow, Sociable Weaver, Neddicky and Ant-eating Chat. The first two species nest on telephone poles, while the latter two species use these for display sites or hunting perches (Ant-eating Chat).

Of the Karoo endemics, Large-billed Lark was positively significantly associated only with increasing green scores, while Sclater's Lark was only associated with water presence (albeit with small sample size at n = 7); and for Karoo Eremomela grass cover was the only significant predictor, with the association being negative. Similarly, for Cinnamon-breasted Warbler, which was also negatively associated with increasing sand cover, but likely positively associated with greater rock cover: a variable not included due to its negative correlation with sand cover. There were no significant predictors of Karoo Lark nor Karoo Korhaan presence from this set of variables.

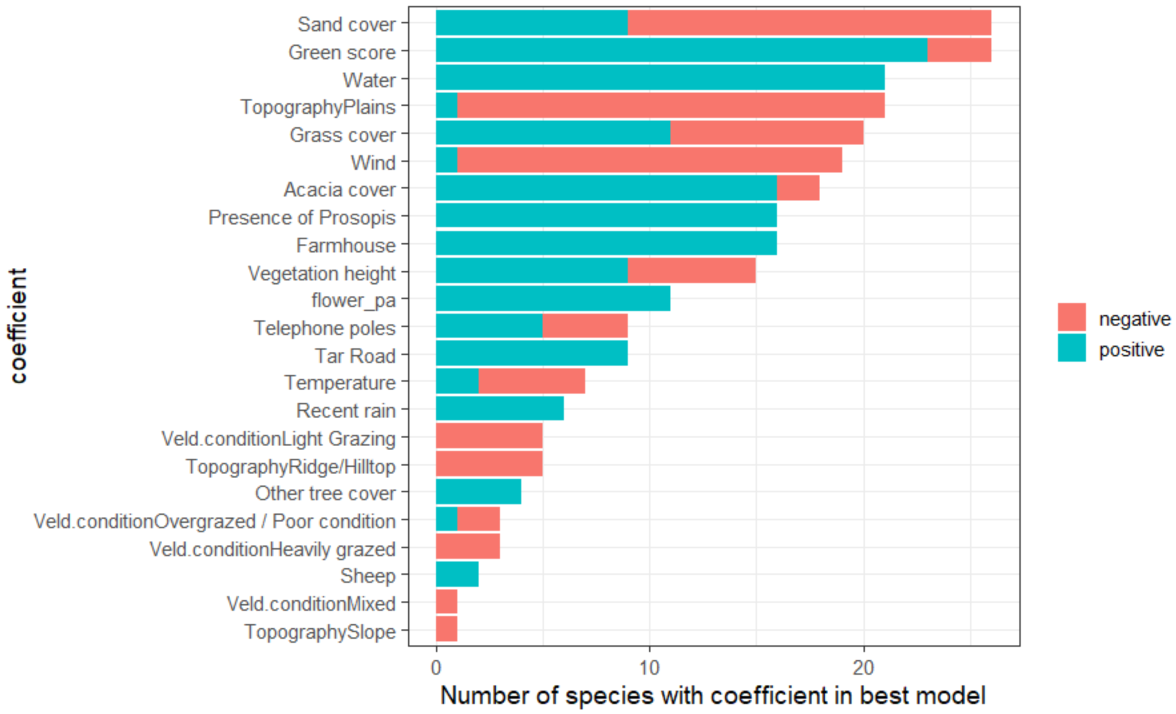


Figure 26: Top predicting variables of 101 species presence at point counts across the Karoo. Colour indicates the direction of the predictors (positive or negative).

The relationship between reporting rate and densities in pentads

Using all 2017 pentads (n = 64), there was a significant relationship between reporting rates and density for 11 of the 20 most common species we obtained density estimates for; but the relationship was stronger for reporting rates and number of clusters (which could be viewed as territories or groups), where there was a significant relationship for 15 (75%) species. Species for which there was no relationship between cluster rates and reporting rate were: Familiar Chat, Karoo Scrub-robin, Pied Crow and Rufous-eared Warbler, with Karoo Prinia nearly significant with p=0.08. Generally, there was a higher probability of reporting rate being 100% with increasing cluster density: patterns are illustrated in Figure 27. However, applying a selection criteria of 4 cards or more (a suggested threshold for analysis of data at the pentad level), this reduced the number of pentads to test the relationship to 15, greatly reducing power and hence at this level no significant relationships were found.

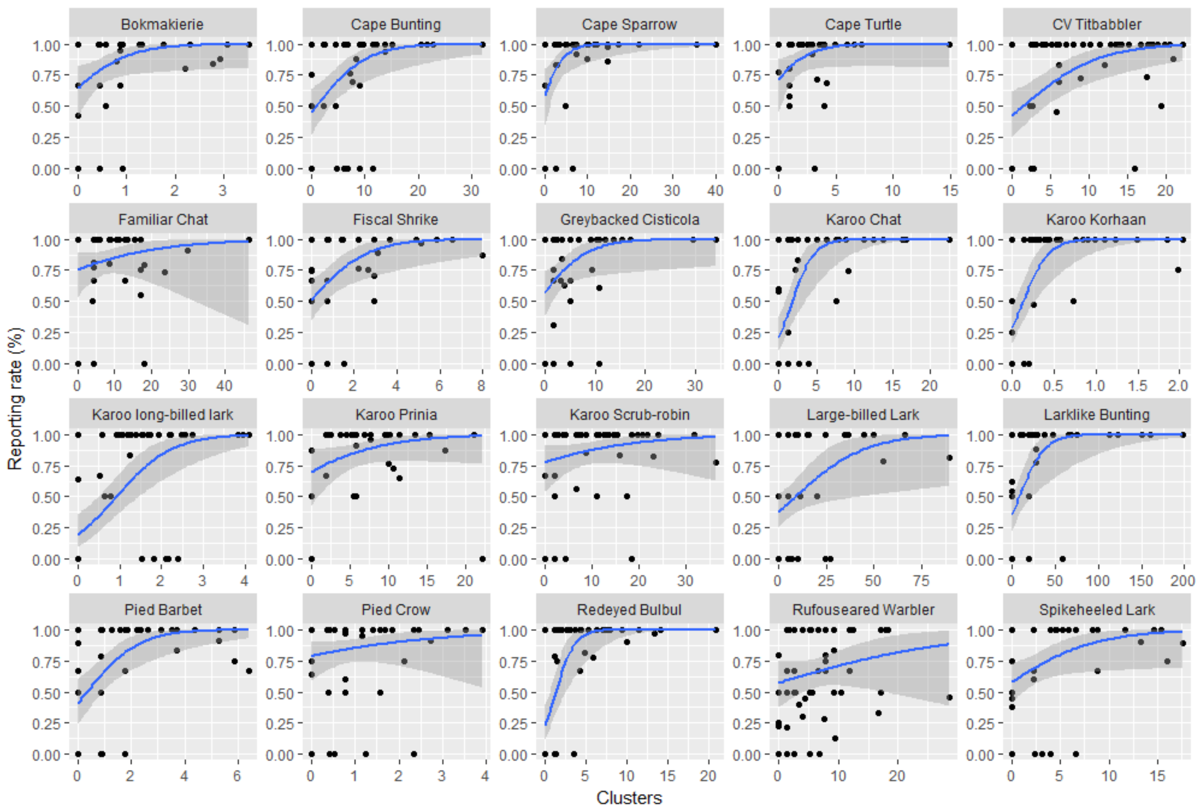


Figure 27: The relationship between SABAP2 reporting rates and number of groups of birds encountered per km^2 (clusters) in pentads covered in this survey. Charts of the relationships between density and reporting rate is similar for this set of species, but generally with wider confidence intervals. Blue lines indicate logistic regression slopes, with standard error as grey shading.

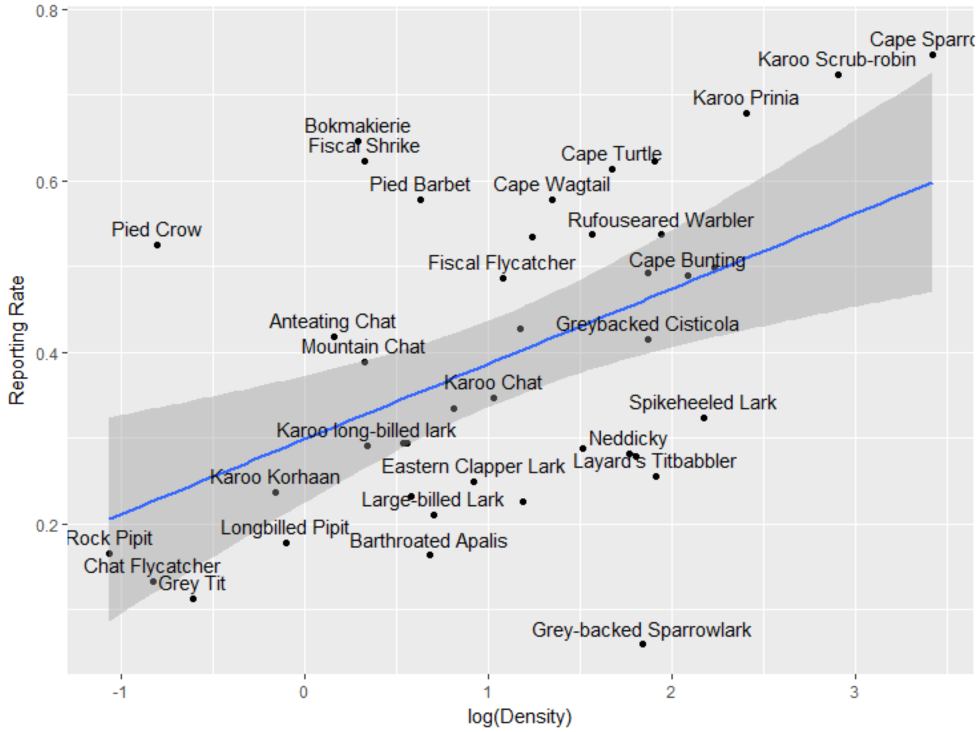


Figure 28: Species mapped according to their mean reporting rate over the 2015-2017 period and densities across the 64 pentads covered during 2017. Reporting rate was significantly explained by a linear model including log of Density plus log Mass for the set of species with density error metrics <0.5.

We obtained density estimates for the 2017 survey for 49 Karoo species (Table 2). The most common according to this output was Lark-like Bunting. However, this was also one of five species with a lower confidence measure of the density estimate, as measured by the ratio of standard error of the density estimate to the mean density estimate. This error metric threshold is subjective based on intuitive familiarity with the species and the environment that provides a good threshold for identifying species with unreasonable density estimates. Statistically, species with a high error could have a wider range of possible density estimates. The following six species had error metrics >0.5: Lark-like Bunting, Southern Masked Weaver, Karoo Lark, Yellow Canary, Egyptian Goose and Pale-chanting Goshawk. High overall density estimates for Lark-like Bunting probably resulted from regionally super high abundance, but absence in many other pentads. Similarly, Southern Masked Weaver density estimates are likely inflated by high counts associated with conspicuous nesting colonies or farmsteads: they are not common in the overall Karoo landscape. High error rates for the other three species are likely a function of lower numbers of detections, as such the Distance software struggled to find appropriate detection functions.

Species specific reporting rates were significantly correlated with their mean density estimates, with better model fits for log transformed data (illustrated in Figure 28). Of interest is that higher reporting rates than expected for density (those species above the regression line) were previously also reported for Cape Turtle Dove and Bokmakierie from the Fynbos biome: these species have loud distinctive calls making them detectable from far away.

Using the model identified to explain reporting rate as a function of density to predict densities for the five species with high density estimate error rates (paragraph above) resulted in far more intuitively reasonable density estimates. Using this predictive model, Karoo Prinia was the most abundant species in this study region, followed by Karoo Scrub-robin, Cape Sparrow, and Rufous-eared Warbler. Lark-like Bunting was however relegated to position 21 (see Table 2).

Table 2: Density and group density (cluster) estimates for 49 species from the southern Karoo, 2017. Standard error (se) of the estimates are provided. The ratio of se to estimate is provided: high values (>0.5) indicate lower confidence in the density estimate. ESW = effective strip width, a measure of how far these species could be reasonably expected to be detected to. Predicted density estimates with standard error from the predictive model based on reporting rates and mass are also provided. Karoo endemics in **bold**.

Species	Clusters	Cluster_se	Density	Density_se	ESW	pred_D	pred_se
Larklike Bunting	18.37	9.94	46.47	25.87	200.04	3.11	1.16
Cape Sparrow	5.91	1.01	30.61	8.14	215.65	8.28	1.31
Southern Masked Weaver	5.20	2.18	29.46	15.58	120.00	5.61	1.24
Karoo Scrub-robin	11.32	0.94	18.33	1.54	213.46	9.08	1.30
Karoo Lark	**9.07**	**25.34**	**14.54**	**40.66**	**237.00**	**1.20**	**1.27**
Yellow Canary	3.47	7.20	13.24	22.93	246.00	2.11	1.20
Karoo Prinia	6.89	0.69	11.07	1.13	206.28	11.06	1.32
Chestnut-vented Titbabbler	7.11	0.79	9.30	1.07	177.24	5.17	1.18
Spike-heeled Lark	2.93	1.23	8.77	3.72	286.20	2.44	1.14
Cape Bunting	5.05	0.59	8.04	0.96	181.36	4.29	1.15
Rufous-eared Warbler	4.75	0.40	6.95	0.60	245.64	6.79	1.23
Layard's Titbabbler	5.31	1.10	6.79	1.43	162.00	2.60	1.19
Familiar Chat	5.04	1.13	6.73	1.53	240.30	6.36	1.23
Grey-backed Cisticola	4.52	0.52	6.49	0.76	189.64	4.48	1.18
White-throated Canary	2.91	0.58	6.48	1.31	220.50	4.03	1.15
Grey-backed Sparrowlark	1.64	0.50	6.31	2.18	206.00	1.37	1.30
Sickle-winged Chat	3.65	0.89	6.09	1.51	174.60	2.43	1.16
Neddicky	4.13	1.35	5.87	1.95	252.00	3.34	1.21
Cape Turtle Dove	1.84	0.23	5.35	1.39	341.36	2.85	1.31
Red-eyed Bulbul	2.49	0.45	4.80	0.89	273.60	4.40	1.17
Red-faced Mousebird	0.70	0.28	4.54	1.82	293.00	1.62	1.18
Cape Wagtail	1.77	0.49	3.85	1.21	130.00	5.80	1.20
Cape Robin-chat	3.13	0.62	3.46	0.69	264.60	4.16	1.17
Namaqua Warbler	**1.64**	**0.69**	**3.29**	**1.37**	**164.00**	**2.57**	**1.21**
Pied Starling	0.33	0.08	3.24	1.07	450.00	1.93	1.22
Fiscal Flycatcher	2.11	0.46	2.95	0.66	267.30	4.01	1.15
Karoo Chat	2.13	0.26	2.81	0.35	258.49	2.39	1.14
Eastern Clapper Lark	1.58	0.30	2.52	0.49	321.33	1.89	1.17
Fairy Flycatcher	1.66	0.43	2.25	0.58	143.00	4.81	1.26
Large-billed Lark	1.49	0.16	2.02	0.23	235.52	1.45	1.20
Egyptian Goose	0.29	0.16	2.02	1.28	400.00	0.54	1.71
Bar-throated Apalis	1.19	0.29	1.98	0.48	307.02	2.25	1.25
Acacia Pied Barbet	1.52	0.21	1.88	0.26	307.02	4.83	1.19
Yellow-bellied Eremomela	1.35	0.34	1.79	0.48	280.00	3.08	1.24
Pririt Batis	1.19	0.32	1.75	0.47	250.00	3.48	1.21
African Pipit	1.13	0.28	1.71	0.44	195.00	2.34	1.15
Karoo long-billed lark	**0.87**	**0.15**	**1.41**	**0.25**	**278.10**	**1.83**	**1.16**
Mountain Chat	1.08	0.24	1.39	0.32	216.00	2.59	1.14
Southern Fiscal	1.28	0.20	1.38	0.23	294.12	4.99	1.22
Bokmakierie	0.85	0.17	1.34	0.26	210.00	4.46	1.25
Ant-eating Chat	0.55	0.11	1.18	0.25	315.00	2.56	1.15
Long-billed Pipit	0.61	0.14	0.90	0.21	270.00	1.52	1.21
Karoo Korhaan	**0.37**	**0.08**	**0.86**	**0.19**	**540.00**	**0.36**	**1.67**
Grey Tit	0.34	0.08	0.55	0.13	257.00	1.51	1.26
Pied Crow	0.18	0.04	0.45	0.14	600.00	1.28	1.46
Chat Flycatcher	0.35	0.08	0.44	0.11	250.00	1.28	1.24
African Rock Pipit	0.26	0.05	0.34	0.07	350.00	1.49	1.22
Pale Chanting Goshawk	0.24	0.20	0.24	0.20	600.00	0.65	1.54
White-necked Raven	0.02	0.01	0.06	0.03	500.00	0.60	1.54

Range specific density estimates and population estimates for within the Karoo

By far the most abundant bird across the South African Karoo landscape (Table 3) is the Lark-like Bunting, with the highest density estimates (56 – 89 individuals/km^2), a large range within the Karoo (>244 thousand km^2), and resulting population estimate of 13.8 – 21.8 million. By contrast, of the 78 species for which we were able to obtain density estimates, White-necked Raven had the lowest (0.05 ind/km^2). Barlow's Lark was recorded from the smallest area (311 km^2), and hence the lowest population estimate 3500 – 13 000. Karoo Scrub-robin was the most widespread species, with a range within the survey area of 305 000 km^2. It was disappointing that insufficient information was obtained to calculate density estimates for most raptors (only Rock Kestrel and Pale-chanting Goshawk). Like-wise, we were unable to obtain a population estimate for Blue Crane or Kori Bustard. The populations of these 2 species can be presumed to be very low in the Karoo (estimated <10 000). Likewise, most raptor species, with the possible exception of Greater Kestrel.

Table 3: Range specific density estimates for birds of the Karoo biome. Density estimate is number of individuals / km^2, together with standard error (se), and estimate range (lower confidence limit LCL to upper confidence limit (UCL)). The population estimates are obtained by multiplying the density estimates, LCL and UCL by the Area (size in km^2 of the Minimum Convex Polygon containing all points where a species was recorded during the 2 year survey). For the Karoo endemic bird species, these population estimates would be representative of the best estimates of the species populations in South Africa (Red Lark, Cape Long-billed Lark), while for those with ranges outside the Karoo, these estimates are only for the population within the South African Karoo region.

	Density				**Population estimate**			
Species	Estimate	se	LCL	UCL	Estimate	LCL	UCL	Area
Lark-like Bunting	71.06	8.35	56.48	89.40	17381020	13814974	21867566	244613
Sociable Weaver	40.50	10.73	24.25	67.63	1308060	783324	2184307	32297
Barlow's Lark	22.04	6.93	11.82	41.12	6848	3671	12774	311
Grey-backed Sparrowlark	20.94	3.89	14.58	30.08	4059734	2826245	5831568	193868
Cape Sparrow	20.27	2.96	15.24	26.96	6095929	4583245	8107870	300726
Black-eared Sparrowlark	18.24	3.41	12.67	26.27	1124278	780783	1618890	61622
Southern Masked Weaver	13.95	4.11	7.92	24.56	3250206	1845981	5722616	233000
Karoo Scrub-robin	10.18	0.89	8.57	12.09	3104597	2613392	3688127	305008
White-throated Canary	9.02	1.13	7.06	11.52	2450037	1918116	3129468	271563
Black-chested Prinia	8.85	2.40	5.23	14.99	561540	331650	950783	63448
Karoo Prinia	8.63	0.70	7.36	10.11	2227119	1900681	2609623	258110
Spike-heeled Lark	8.30	0.94	6.65	10.36	2366425	1896265	2953156	284945
Stark's Lark	7.92	2.02	4.83	13.01	421820	256980	692395	53228
Cape Long-billed Lark	**7.77**	**1.03**	**5.99**	**10.10**	**37666**	**29002**	**48917**	**4845**
Sabota Lark	7.12	0.68	5.92	8.58	1095983	910389	1319413	153862
Chestnut-vented Titbabbler	7.07	0.72	5.79	8.63	1583424	1297232	1932754	223945
Rufous-eared Warbler	6.89	0.75	5.56	8.53	2091992	1689186	2590854	303588
Cape Bunting	6.35	0.77	5.01	8.07	1742175	1372474	2211462	274199
Yellow Canary	6.04	1.88	3.32	10.99	1623325	891665	2955353	268913
Karoo Lark	5.80	0.64	4.68	7.19	760125	612889	942732	131079
Sickle-winged Chat	5.45	1.22	3.51	8.45	1008456	650396	1563637	185068
Familiar Chat	5.38	0.96	3.79	7.64	1581487	1114683	2243778	293875
Grey-backed Cisticola	5.20	0.47	4.36	6.22	1550373	1297880	1851988	297967
White-backed Mousebird	5.07	1.48	2.89	8.88	1071342	611272	1877682	211454
Layard's Titbabbler	4.91	0.59	3.88	6.22	1322670	1044042	1675657	269206
Ludwig's Bustard	4.91	0.59	3.88	6.22	1322670	1044042	1675657	269206
Cape Turtle Dove	4.79	1.14	3.02	7.61	1382692	871278	2194291	288419
Speckled Pigeon	4.62	1.91	2.11	10.16	1274442	580263	2799080	275631
Karoo Eremomela	4.52	1.23	2.67	7.66	409250	241492	693546	90513
Red-eyed Bulbul	4.46	0.59	3.44	5.78	734625	566935	951915	164758
Dusky Sunbird	4.24	0.64	3.15	5.70	1062502	789926	1429134	250695
Yellow-bellied Eremomela	4.17	0.45	3.38	5.15	921912	747080	1137659	220886
Namaqua Warbler	3.48	1.10	1.88	6.44	439611	237297	814412	126445
Southern Double-collared Sunbird	3.35	0.63	2.31	4.84	802773	554893	1161385	239927
Red-capped Lark	3.23	0.73	2.08	5.00	725065	467750	1123932	224622
Red-faced Mousebird	3.19	1.07	1.66	6.10	735955	383970	1410602	231061
Pririt Batis	3.00	1.11	1.47	6.10	655706	321826	1335971	218906
Tractrac Chat	2.87	0.44	2.13	3.88	450248	333975	607000	156643

Species	Estimate	se	LCL	UCL	Estimate	LCL	UCL	Area
Large-billed Lark	2.83	0.28	2.34	3.43	783365	646666	948961	276431
Karoo Chat	2.79	0.27	2.30	3.37	619822	512039	750292	222408
Namaqua Dove	2.75	1.03	1.34	5.67	640090	311143	1316808	232423
Eastern Clapper Lark	2.69	0.45	1.95	3.73	376969	272291	521889	139941
Cape Robin	2.60	0.46	1.83	3.68	536189	378072	760434	206377
Pied Starling	2.49	0.67	1.48	4.18	441197	262809	740671	177123
South African Shelduck	2.32	1.76	0.62	8.72	456800	121657	1715209	196586
Cape Wagtail	2.32	0.60	1.40	3.83	526235	318423	869669	227245
Fairy Flycatcher	2.24	0.39	1.60	3.14	470804	335793	660098	210237
Black-headed Canary	2.23	1.26	0.78	6.35	455492	159852	1297910	204351
Fiscal Flycatcher	2.18	0.47	1.44	3.32	451746	297216	686620	207113
Mountain Chat	1.95	0.35	1.38	2.76	424819	300038	601494	217871
Longbilled Crombec	1.91	0.34	1.36	2.70	549931	390107	775235	287381
African Stonechat	1.86	0.49	1.11	3.12	400132	238738	670634	215181
Malachite Sunbird	1.75	0.50	1.01	3.05	429312	246363	748120	245127
Namaqua Sandgrouse	1.69	0.36	1.12	2.56	382509	252556	579330	226176
Common Quail	1.66	0.35	1.10	2.49	197890	131426	297965	119480
Laughing Dove	1.48	0.46	0.81	2.72	355216	193729	651314	239762
Red Lark	**1.42**	**0.30**	**0.94**	**2.14**	**47779**	**31665**	**72093**	**33729**
Chat Flycatcher	1.36	0.12	1.15	1.61	334734	283334	395459	245623
African Pipit	1.25	0.23	0.87	1.80	285646	198275	411518	228128
Acacia Pied Barbet	1.21	0.15	0.96	1.54	325642	256818	412910	268245
Karoo Long-billed Lark	1.19	0.10	1.02	1.40	298340	254073	350319	249780
Rock Martin	1.16	0.88	0.30	4.48	305726	78820	1185840	264660
Bokmakierie	1.14	0.08	0.99	1.31	338276	294470	388599	296167
Egyptian Goose	1.00	0.43	0.45	2.26	198154	88109	445643	197349
Grey Tit	0.83	0.14	0.59	1.16	219550	156522	307958	265629
Capped Wheatear	0.80	0.18	0.52	1.24	107657	70080	165381	133883
Rock Pipit	0.79	0.42	0.29	2.15	84995	31158	231860	108023
Fiscal Shrike	0.75	0.07	0.62	0.91	226046	186746	273618	301644
Pale-winged Starling	0.74	0.37	0.28	1.93	123144	46941	323055	167128
Karoo Korhaan	0.71	0.10	0.54	0.94	148206	113027	194334	207418
Cinnamon-breasted Warbler	0.63	0.22	0.32	1.24	61304	31356	119855	96756
Ant-eating Chat	0.62	0.07	0.50	0.77	171990	137622	214942	277931
Northern Black Korhaan	0.45	0.06	0.35	0.58	59154	45757	76475	130786
Pied Crow	0.43	0.11	0.26	0.70	126221	76816	207402	296578
Rock Kestrel	0.25	0.26	0.04	1.53	59911	9915	362003	237196
Pale Chanting Goshawk	0.20	0.07	0.10	0.39	53829	27375	105848	272687
White-necked Raven	0.05	0.03	0.02	0.13	7790	3034	20002	148739

Reporting rate trends from SABAP2

No species exhibited alarming trend in changes in reporting rate between years for the set of endemic bird species. Reporting rates calculated as the mean across the range per year. Example charts of mean reporting rate across a species range is given for an example set of the Karoo endemic birds below (Figure 29).

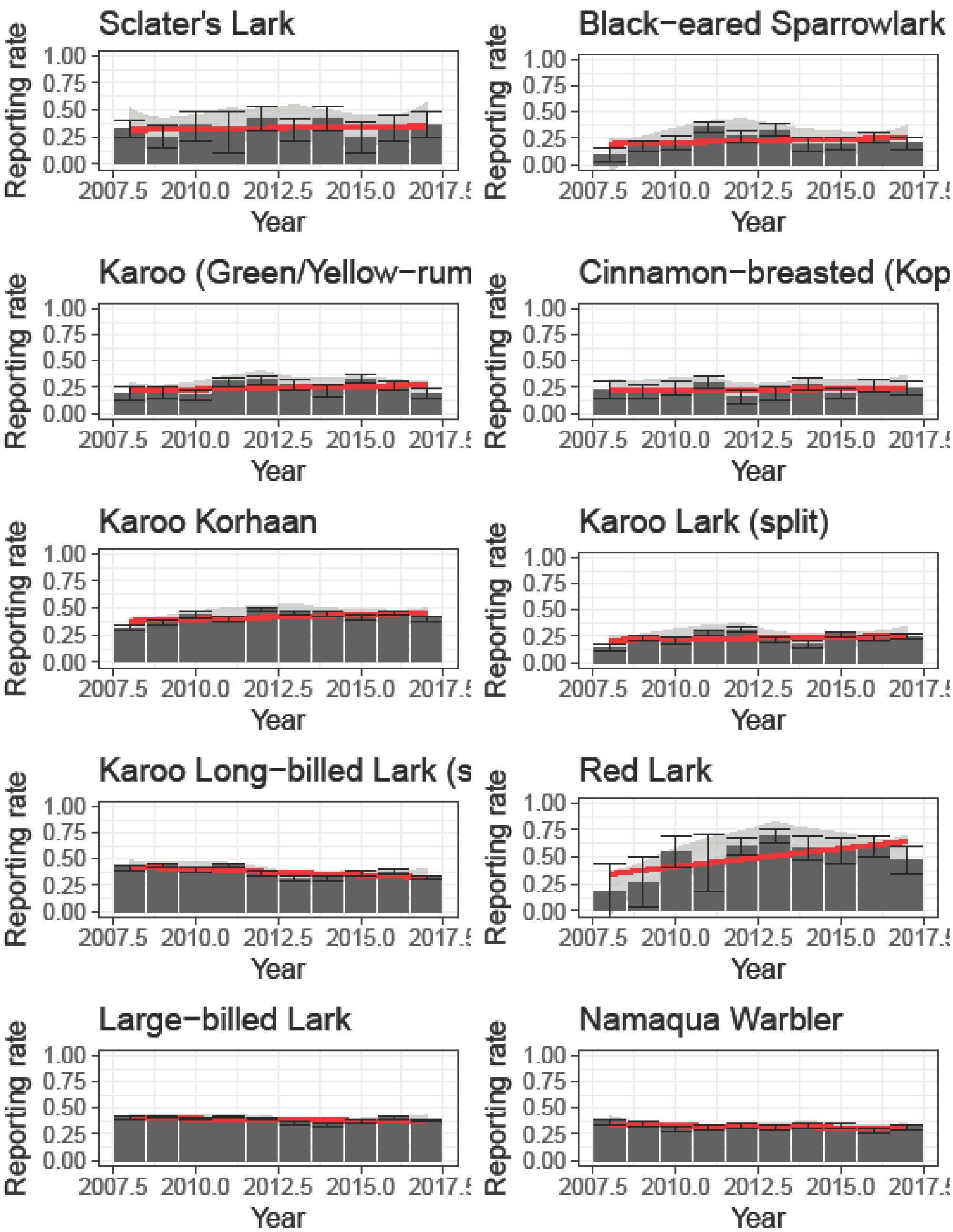


Figure 29: Year on year mean reporting rates across each species range. Thick bar is the mean, error bars are standard error of the mean, while the red line is a regression of year on reporting rate, overlaid on the standard error of a loess regression (grey shading). Reporting rate is given as a proportion rather than a percentage.

Also interesting are the spatial-temporal patterns of species occurrence derived from SABAP2 data: in the figure below are reporting rates for Lark-like Bunting by year (Figure 30). A 'standard' year can be seen in 2012, followed by the irruption of 2013 – which can clearly be seen, but was generally poorly documented in the media (but see this report from SANPARKS: https://www.sanparks.org/assets/docs/groups_birders/public_sightings/2013-kruger.pdf). In 2015 the Western Cape had reasonable rains, while the north-west experienced drought, resulting in a south-west shift in the reporting rate pattern. The drought in the Western Cape in 2017 is then again clearly reflected in the distribution of Lark-like Bunting, which retracts to the eastern Nama Karoo region, which did experience reasonable rains over the summer of 2016/2017. The pattern is similar, but not as clear, for Grey-backed Sparrowlark. By contrast, the mostly resident Karoo Chat shows a very stable year to year distribution (Figure 31).

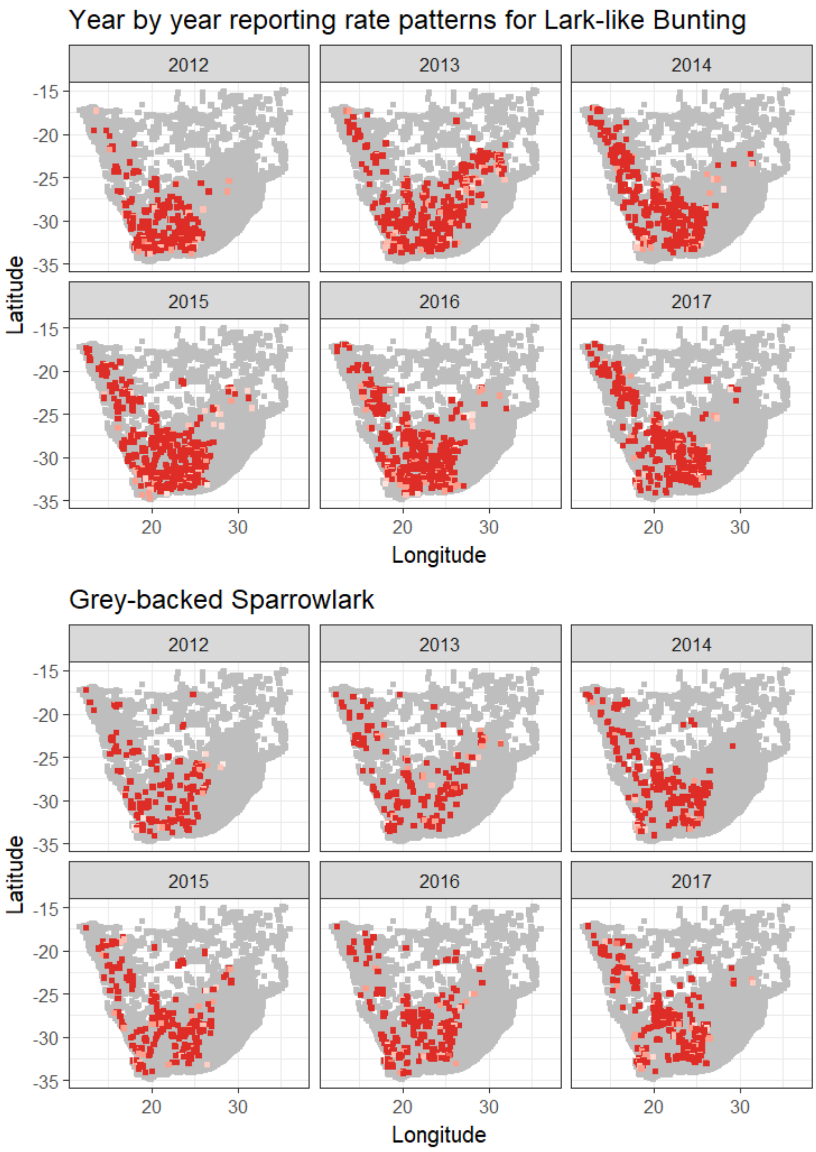
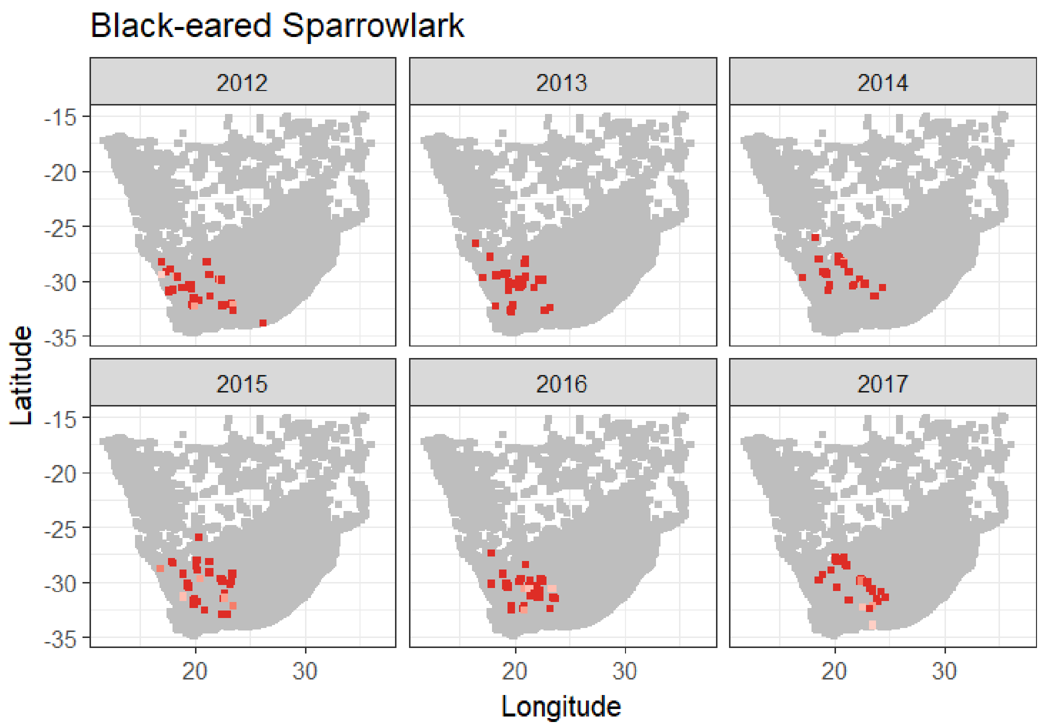


Figure 30: Inter-annual reporting rate patterns across southern Africa for two nomadic species, Lark-like Bunting (top) and Grey-backed Sparrowlark (below). These species are likely responding to local resource availability, with irruptions resulting from poor conditions following good breeding years. The conditions behind the 2013 irruption of Lark-like Bunting merits further investigation.



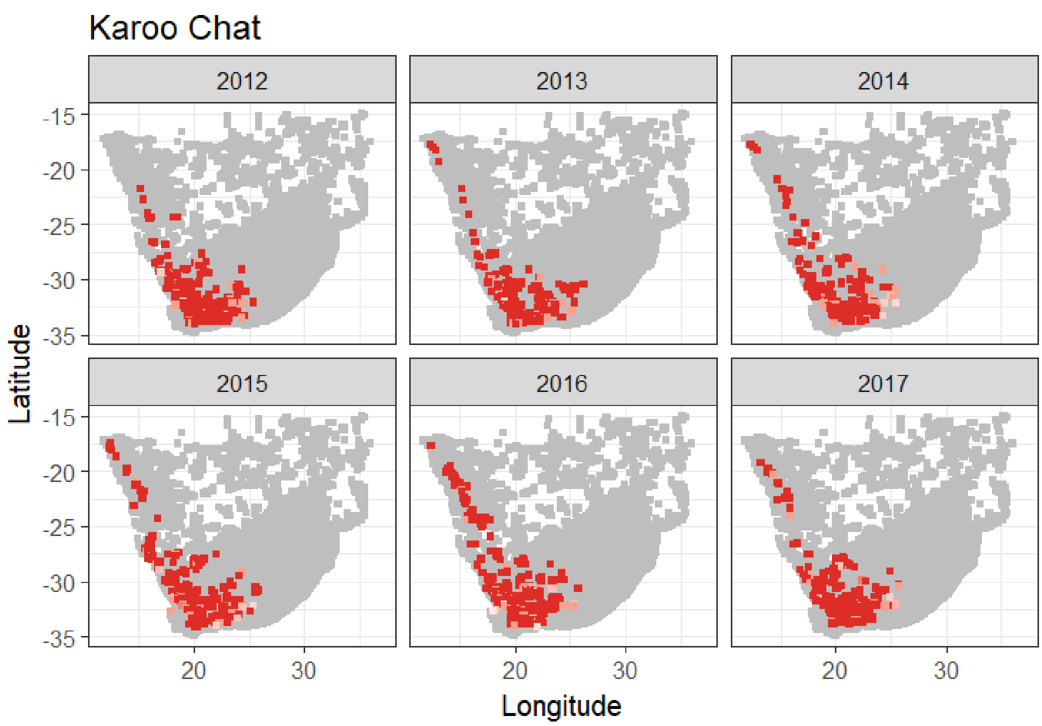
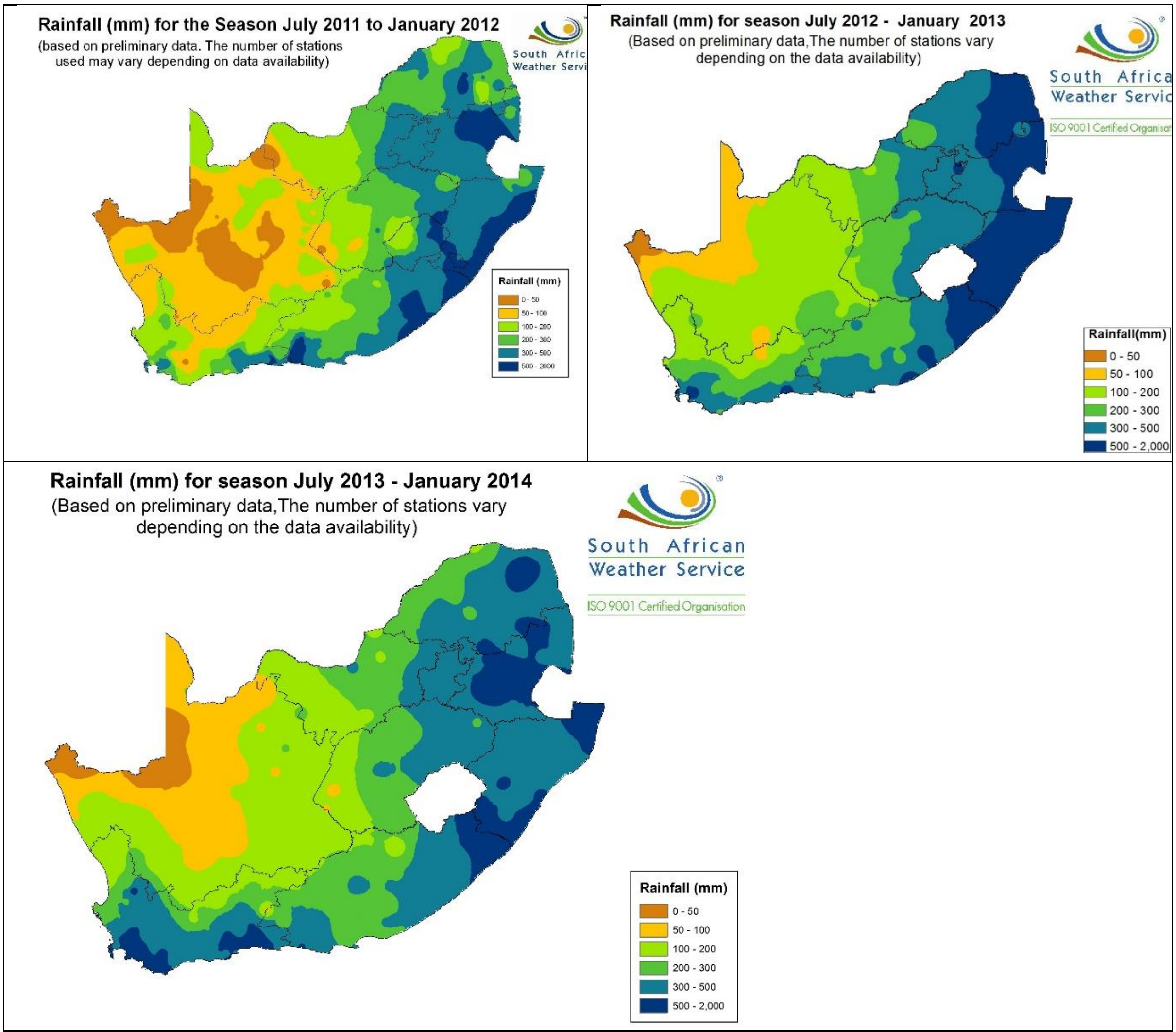
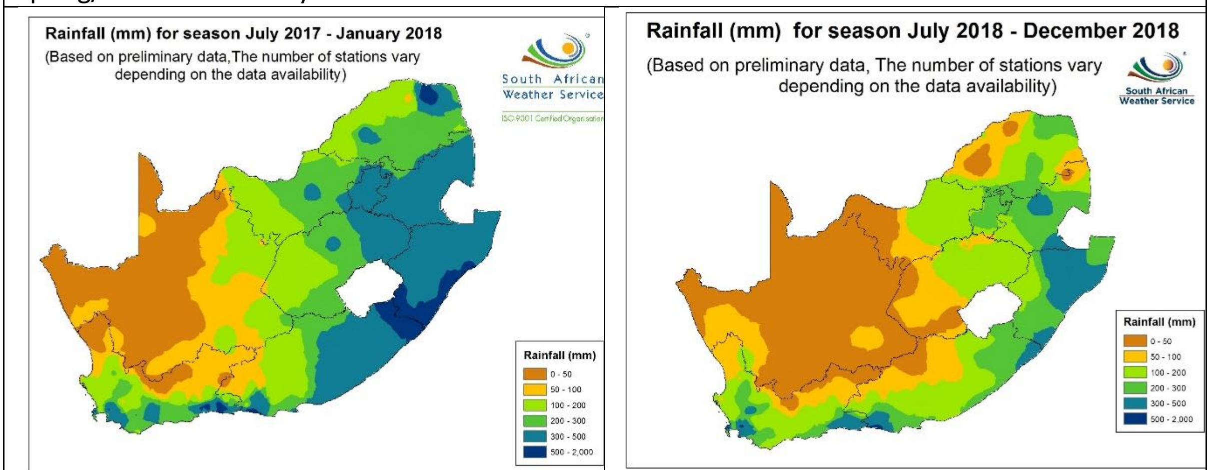


Figure 31: Year by year reporting from SABAP2. Karoo Chat range is stable across South Africa, and suggest that 'irruptive' patterns for any species appearing in Namibia should be ignored until there is better atlasing coverage in that country. Black-eared Sparrowlark also exhibits a dynamic range through years, suggesting that for irruptive species realised range should be a mean of the ranges by year, rather than a sum of occurrence records throughout recorded time.



Rainfall for late 2011, and the conditions leading to the Lark-like bunting irruption in 2013: a good spring/summer rainfall year towards the end of 2012 across much of the Karoo.



Count conditions for 2017 / 2018 were dry, following several drought years.

Figure 32: Interpolated total annual rainfall for 2012-2013 compared to 2017-2018, from the South African Weather Service. Maps available from: http://www.weathersa.co.za/climate/historical-rain-maps

Drinking dependence and heat avoidance/dissipation behaviour

During point counts behavioural observations were recorded for species if group behaviour and time allowed. Of interest in an arid environment is which species are recorded drinking. As such, we present the species in Table 4, which indicates of species observed 5 or more times during the survey (168 species), the 29 species which were observed drinking, including the number of groups that were observed drinking, and then a 'water dependence' score calculated as the number of groups observed drinking divided by the total number of groups. Small, granivorous species dominated the set of species with a dependence score >0.04. This table is by no means comprehensive: other species e.g. Pale-winged Starling were observed drinking outside point count periods. Also, water birds were not monitored for drinking behaviour. On the whole, this is a set of birds which is benefitting from current livestock farming of water provisioning, but also a set of species that may be adversely impacted by decrease in rainfall or contamination of water sources.

Table 4: Bird species that were observed drinking during point counts, showing total number of groups encountered, the number of groups for which drinking was recorded (Drinking), and the derived 'water dependence' i.e. drinking divided by groups. Species are ranked by dependence

Common name	Total groups	Drinking	dependence
Sclater's Lark	9	4	0.444
Red-headed Finch	32	5	0.156
Black-throated Canary	10	1	0.100
Southern Grey-headed Sparrow	20	2	0.100
Speckled Pigeon	88	7	0.080
Southern Red Bishop	28	2	0.071
Black-headed Canary	72	5	0.069
White-throated Canary	269	18	0.067
Southern Masked Weaver	144	9	0.063
Cinnamon-breasted Bunting	17	1	0.059
Yellow Canary	200	11	0.055
Namaqua Dove	94	5	0.053
Red-billed Quelea	20	1	0.050
Cape Sparrow	433	21	0.048
Lark-like Bunting	1205	55	0.046
Red-capped Lark	88	4	0.045
African Red-eyed Bulbul	150	6	0.040
Little Swift	30	1	0.033
Sociable Weaver	62	2	0.032
Grey-backed Sparrow-Lark	513	10	0.019
Laughing Dove	66	1	0.015
Pied Starling	70	1	0.014
Cape Bunting	380	5	0.013
Namaqua Sandgrouse	366	4	0.011
Large-billed Lark	294	3	0.010
Ring-necked Dove	305	3	0.010
Chestnut-vented Warbler	229	2	0.009
Rock Martin	132	1	0.008
Sabota Lark	320	1	0.003

Information was also taking on heat dissipation or avoidance behaviour: but this was rarely observed (44 times of 2003 group observations for 31 species; Table 5, Table 6). It should be remembered that count conditions during the spring period were cold to mild and rarely above 30C.

Table 5: Number of groups of birds observed undertaking 'classical' heat dissipation behaviours.

Heat dissipation	**Count**
Shade seeking	38
Wing drooping	1
Panting	5
None	1959
Total	**2003**

Table 6: A 'heat vulnerability' score was calculated as the sum of heat dissipation (shade seeking, wing drooping, panting) divided by the total number of observations for which no heat dissipation was recorded. The following table is filtered for Total observations >5 observations, representing 25 of the 31 species for which heat avoidance/dissipation behaviour was recorded.

Common name	**Shade**	**Drooping**	**Panting**	**None**	**Total**	**dissipation**	**vulnerable**
Speckled Pigeon	3	0	0	7	10	3	0.3
Black-headed Canary	1	0	0	5	6	1	0.167
Speckled Mousebird	1	0	0	5	6	1	0.167
Long-billed Pipit	0	0	1	6	7	1	0.143
Pied Starling	1	0	0	6	7	1	0.143
Red-faced Mousebird	1	0	0	7	8	1	0.125
Southern Red Bishop	1	0	0	8	9	1	0.111
Malachite Sunbird	1	0	0	9	10	1	0.1
Karoo Eremomela	1	0	0	11	12	1	0.083
Laughing Dove	1	0	0	11	12	1	0.083
Layard's Titbabbler	2	0	0	25	27	2	0.074
Chestnut-vented Titbabbler	1	0	0	13	14	1	0.071
Pririt Batis	1	0	0	13	14	1	0.071
African Pipit	0	0	1	16	17	1	0.059
Familiar Chat	3	0	1	64	68	4	0.059
Mountain Wheatear	1	0	0	22	23	1	0.043
Grey-backed Cisticola	1	0	0	25	26	1	0.038
Karoo Lark	0	0	1	33	34	1	0.029
Karoo Prinia	1	0	0	33	34	1	0.029
White-throated Canary	2	0	0	91	93	2	0.022
Lark-like Bunting	4	0	0	193	197	4	0.02
Sabota Lark	1	0	1	98	100	2	0.02
Tractrac Chat	1	0	0	48	49	1	0.02
Karoo Scrub Robin	0	1	0	60	61	1	0.016
Rufous-eared Warbler	1	0	0	66	67	1	0.015

Spatial distribution modelling of key Karoo endemic species

Prediction maps for Karoo Lark based on survey data and regions of high confidence of absence paint a very different picture of Karoo Lark distribution compared to SABAP2 data (Figure 33a). It is the opinion of AL that SABAP2 data contain a high error rate of presence for the south and east of the species range, given AL's experience in the field plus the modelling results. Worryingly, the SABAP2 range seems to mimic that seen in field guides maps i.e. SABAP2 distribution is merely reflecting range maps as given in field guides. Despite very different mathematics behind the predictive modelling approaches, the final prediction maps are visually very similar, and prediction values are extremely strongly correlated ($t = 150$, $df = 16\ 688$, $p < 0.0001$). However, the predictive techniques were not useful for several species, producing unrealistic distribution maps for several species: due to low numbers of detections, predictive maps for Barlow's and Sclater's Lark were not useful. Likewise, Cinnamon-breasted Warbler distribution maps would require geological structure as a useful predictve layer, given their restricted distribution to dolerite or granite rock dominated landscapes, where red lichen occurs. Namaqua Warbler predictions would require a data layer with drainage lines. Never-the-less, predictive range maps for Red Lark, Karoo Eremomela (Figures 34), Karoo Long-billed Lark and Karoo Korhaan appeared (Figures 35) to be well illustrated using this method.

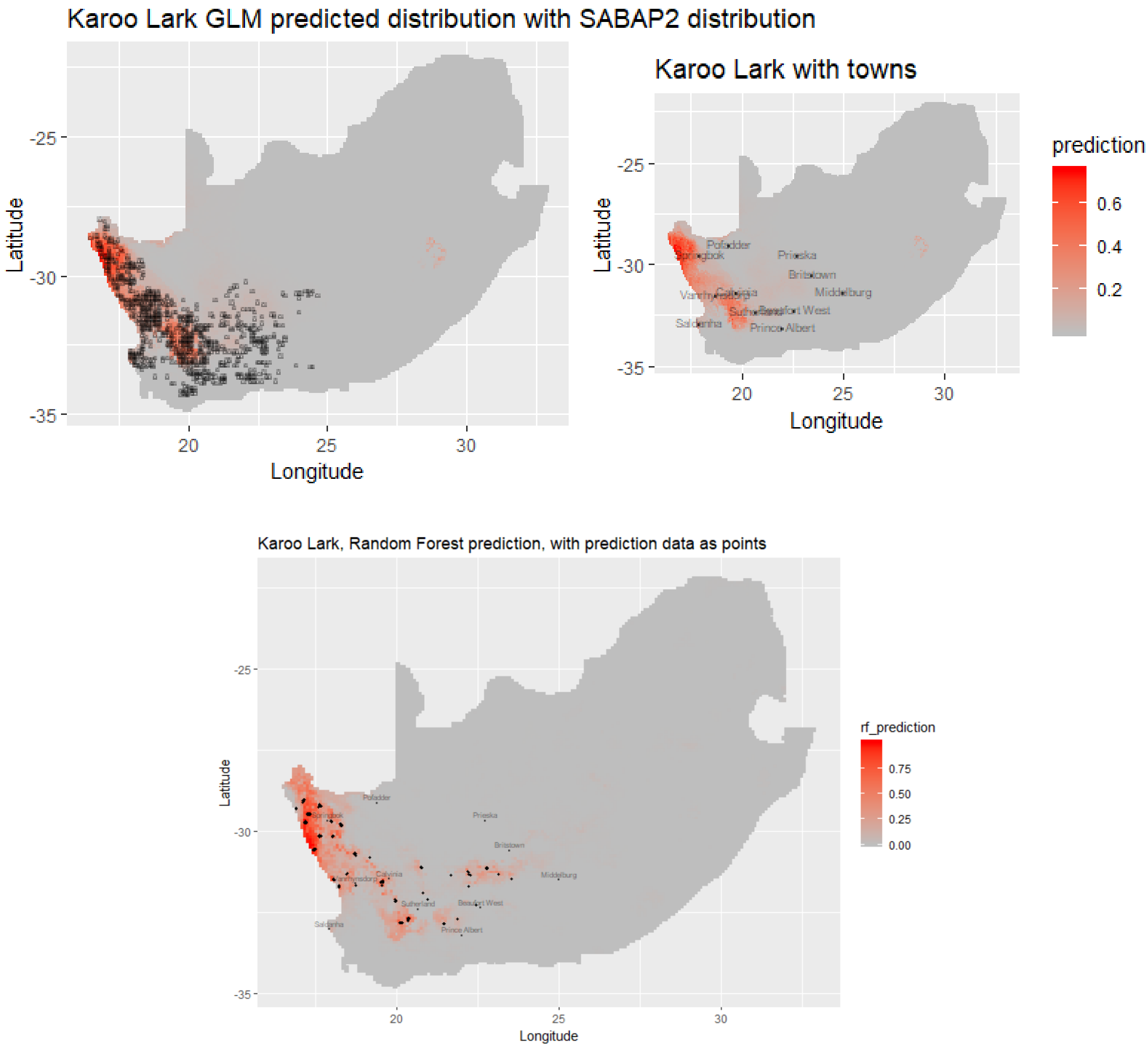


Figure 33: Species range for Karoo Lark as predicted by logistic regression GLM models. SABAP2 distribution is overlaid (top left, squares). The distribution map for the GLM is very similar to that produced from a random forest machine learning method (lower image).

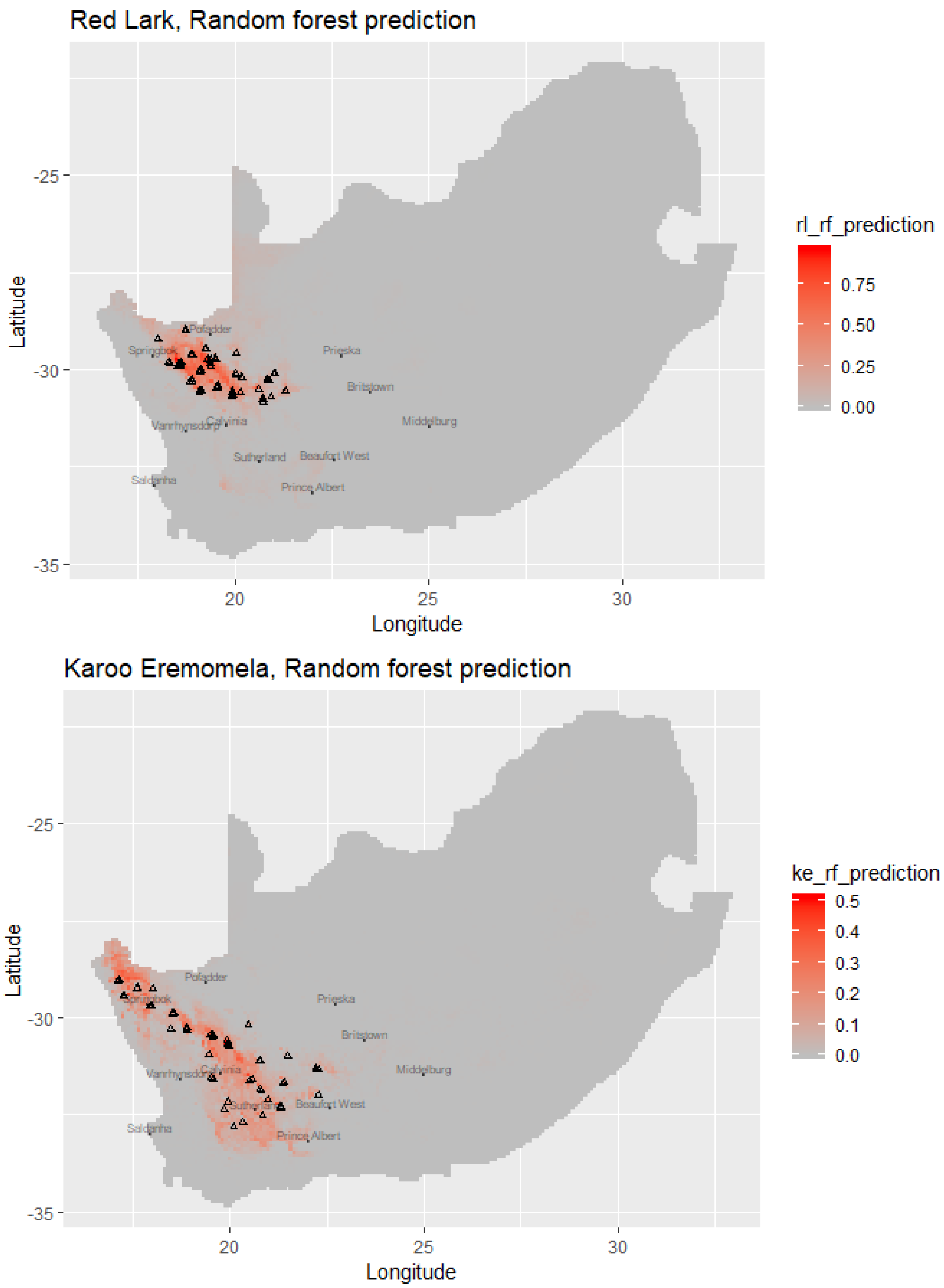


Figure 34: Predictive range maps using the random forest predictive modelling technique for Red Lark and Karoo Eremomela. Red indicates high probability of occurrence, while grey indicates high probability of absence. Detections of the species, i.e. locations used to create the maps, are show as triangles.

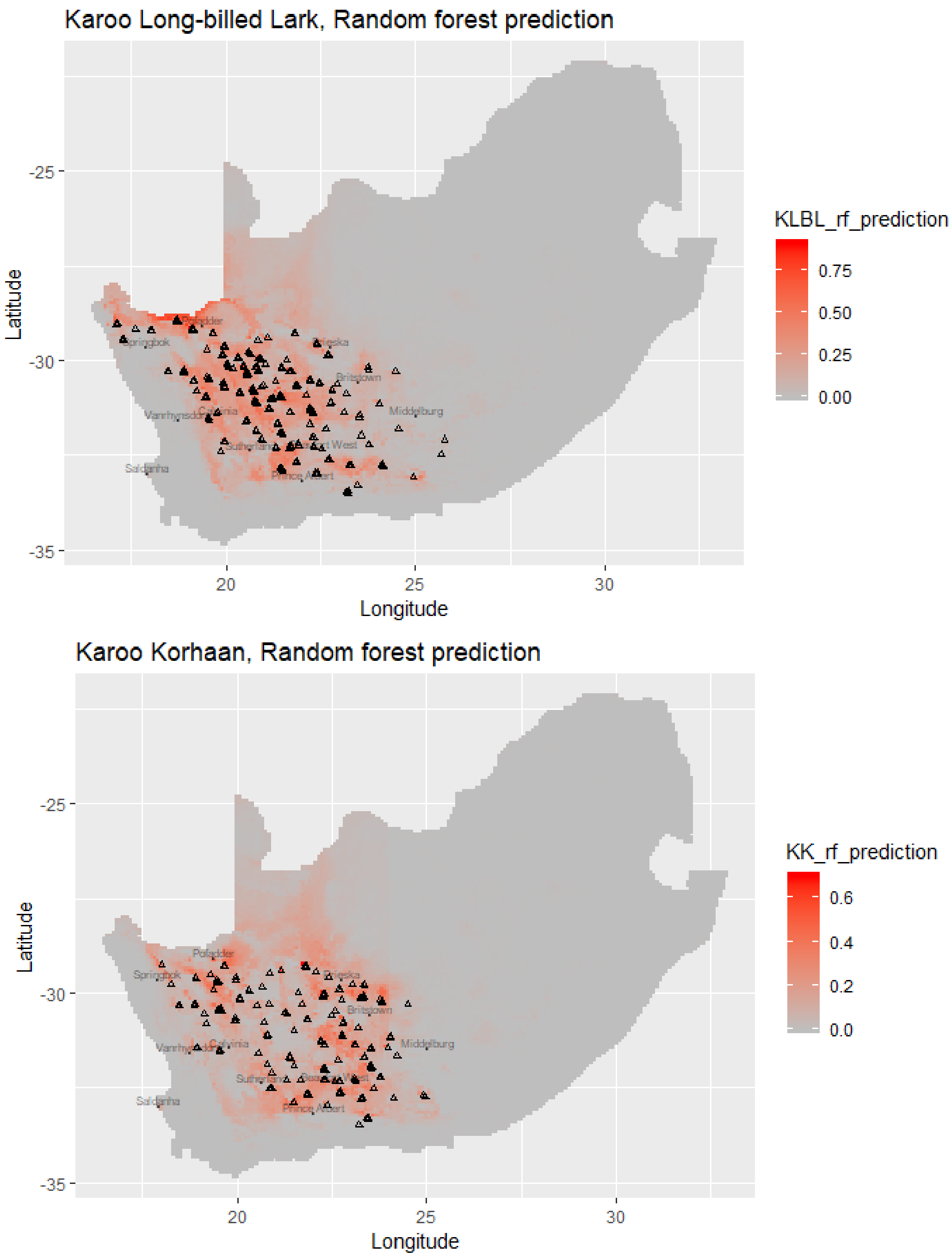


Figure 35: Predictive range maps using the random forest predictive modelling technique for Karoo Long-billed Lark and Karoo Korhaan. Red indicates high probability of occurrence, while grey indicates high probability of absence. Detections of the species, i.e. locations used to create the maps, are show as triangles.

Discussion

Overall patterns of species richness

The increasing total species counts from west to east are synonymous with two broad climatic patterns: increasing rainfall and a change of rainfall patterns from winter through aseasonal, to summer in the north-east. In line with this, the amount of grass cover increased eastwards, as did vegetation biomass: evident as decreasing exposed soil cover and increasing vegetation height. Increasing vegetation height and structural diversity are well known correlates of a wide range of species richness patterns (Huston 1979, Tews et al. 2004). This pattern was expected given the overall increase in bird species richness from west to east across South Africa (Van Rensburg et al. 2002). Van Rensburg et al. (2002) found that taking spatial autocorrelation and area effects into account, that primary productivity, precipitation, absolute minimum temperature, and, at coarser resolutions, habitat heterogeneity account for most variation in species richness across South Africa.

Overall patterns of Karoo endemic species richness

A negative correlation between Karoo endemic bird species richness and percentage acacia cover is of concern given that acacia is associated with thicket encroachment under current land-use and climatic conditions (O'Connor et al. 2014). In addition, acacia is structurally similar to *Prosopis*, an alien vegetation tree increasingly becoming a problem across arid zones of Africa (Dean et al. 2002). Endemic species richness decreasing with increasing grass cover is to a degree an artefact of the spatial association of grass with summer rainfall. Thus, generally Karoo endemism is associated with the winter rainfall regime and Succulent Karoo. The reasons for this require further investigation e.g. physiology, breeding regimes and dietary specialisation associated with resources resulting from vegetation structure, invertebrate communities and phenology associated with low, but generally predictable rainfall.

On a positive note, while at the outset of the project, there was concern regarding low reporting rates of Karoo Eremomela and Cinnamon-breasted Warbler, both these species were generally common and present in appropriate habitat. Cinnamon-breasted Warbler was common in generally inaccessible mountain environments, especially the granite hills of the Namaqualand to Richtersveld district; and dolerite koppies of the Bushmanland region and escarpment. On a more amusing note: as Cinnamon-breasted Warbler were strongly confined to areas with rocky 'klipheuwels', it is unlikely that the prediction of huge abundance increases (348%) in this species are likely (Huntley et al. 2012). Given the highly fragmented range of this species, it remains of interest how dispersal occurs, and as such would make an interesting focal species for genetic and further ecological studies.

Sclater's Lark was encountered extremely infrequently: too infrequently to model densities. The population estimate from the equation relating reporting rate to density estimates is thus the only population estimate available. The lack of any encounters during 2017 with Black-eared Sparrow-lark during formal surveys was also a surprise, although this species was abundantly encountered during 2018 in the Bushmanland area. Of the Karoo species considered in a conservation assessment conducted by Lee et al. (2017a), both Sclater's Lark and Black-eared Sparrow-lark exhibited between atlas (SABAP1 vs SABAP2) apparent range contractions of > 40%, with moderate declines in reporting rate of around 15%. Due to low atlasing efforts across the Karoo, this range decline was deemed to be an artefact of atlasing effort, but the formal survey conducted here during 2017 suggests Sclater's Lark at least may need further conservation attention.

Richard Dean notes: Black-eared Sparrow-lark are more or less restricted to sands, whereas Grey-backed much more catholic in soil and vegetation type. Distribution of Black-eared may also follow the distribution of *Seothyra* sp spiders as Black-eared use *Seothyra* webs in their nests.

Also on a more positive note, the lack of any clear influence of sheep presence suggests that we have identified landowners that could be the target of information dissemination or future conservation efforts targeting Karoo endemic bird species. The caveat exists that heavily and degraded landscapes were more depauperate in species and was negatively correlated for species presence for several species.

Variables associated with higher species richness at the point count level

Highest species counts were generally associated with the presence of water. In the most arid locations, reservoirs were constantly visited by a stream of mostly granivorous species, like Lark-like Bunting, Cape Sparrow, various canary species, and Grey-backed Sparrowlarks. Salamatu Abdu (Abdu et al. 2018) has shown that water points can influence species richness and abundance at small spatial scales (<2km); while a study of fynbos birds has also shown that granivorous birds are most associated with visitation to water points, especially under hotter and drier conditions (Lee et al. 2017b). Also, dams were associated with aquatic birdlife, especially ducks or waders.

Oudebaaskraal Dam, Tankwa

While overall, tar roads did not influence species richness, in the southern Karoo it was found that tar roads were associated with higher species richness compared to dirt or veld points. This was unexpected, given that conventional wisdom is that roads have a negative impact on bird presence (Fahrig and Rytwinski 2009, Rheindt 2003). Of course, traffic on Karoo roads is likely vastly lower than on European or North American roads, which these studies consider. Tar roads are associated with a range of features that could influence detectability, including the presence of telephone poles and fences. During 2017, that tar roads were also significantly associated with the probability of encountering flowers was also interesting: the run-off from asphalt roads could provide critical moisture for plants at the road edges. Certainly, floral displays were rarely observed during this survey, but were noticeable along road edges as illustrated along a section of the N1 near Leeu-Gamka below.

During 2017 flower displays were mostly restricted to road verges

Farmsteads are oases for birds, with high species richness likely facilitated by trees, water and livestock feed.

SABAP2 reporting rate and densities in pentads

For our 2017 survey across the southern Karoo region of South Africa, we obtained density estimates for 49 of 231 species, for which reliable estimates were obtained for 42. Overall density estimates were low, but with large variation between sites for some species. Uncertainty in density estimates was greatest for species with high variability in group sizes. Despite a large survey effort, we did not obtain density estimates for all the Karoo-endemic bird species, notably: Sclater's Lark, Black-eared Sparrowlark and Cinnamon-breasted Warbler, due to low encounter rates.

SABAP2 is considered to be the most important and useful bird monitoring program for southern Africa's Birds, with data used in a wide range of research and conservation applications (Underhill 2016a), including for guiding conservation decisions (Lee et al. 2017a). The primary aim of this analysis was to understand the relationship between density estimates and the putative index of relative abundance obtainable from SABAP2: reporting rate. For most species, higher individual and group densities were associated with a higher probability of the species being reported for that pentad. However, this relationship was non-significant for the most common species, for which reporting rates tended towards 100%. The relationship is thus confounded by low coverage, i.e. small numbers of lists submitted for the pentads in this region. However, a validation of the general pattern of an increased probability of the species being reported with increased abundance is useful. Any changes in general reporting rate patterns (e.g. inter-annual) are thus probably reflective of population change, given that observer effort for SABAP2 is relatively constant, which is the case for the 2010–2015 SABAP2 period. It should be noted that just as we struggled to link reporting rate to density estimates for common species, it has been shown that citizen science projects can also fail to detect declines for common species (Kamp et al. 2016).

Given low atlas coverage with associated uncertainty in obtaining individual species' reporting rate to density estimate relationships, we showed that it was useful to create a single reporting rate summary statistic for each species and examine these against summarised density estimates across the community of birds. In so doing, the relationship between reporting rates and densities was improved by incorporating body mass probably because if all else is equal, larger birds are generally more easily detected, and the larger birds in this dataset also had louder calls. We believe that the density estimates derived from the relationship between density estimates and reporting rates for this community provided more reasonable density estimates for the species for which there was high uncertainty in the single-species modelling. In their study comparing abundance between the Australian Bird Atlas Project and a constant effort monitoring scheme, Szabo et al. (2012) found a generally positive correlation. Thus, this relationship could be exploited for any study where multiple density estimates exist in relation to a metric produced by citizen science efforts to cross-check density estimates.

It should be noted that the equation we present to calculate density from reporting rate should only be used for birds in the Karoo Biome. Lee and Barnard (2017) showed that a similar model for birds of the Fynbos had poor transferability to other biomes: overall bird densities in the Karoo are much lower than those in the Fynbos. In addition, for species with reporting rates tending towards 100%, a minimum density estimate can be calculated, but real density could be orders of magnitude larger.

Threats and opportunities

Land-use change and infrastructure development

Land-use resulting from human activity had a mixed impact on bird species richness. The presence of cattle and sheep on land seemed to have little impact on bird presence, although degraded landscapes did have lower species richness. There is still limited infrastructural development: only two pentads contained wind-turbines, and few counts were associated with major or minor pylons. On one of these, Red Lark was seemingly very common. Although mortality rates were not a focus of this study, it should be noted that one Ludwig's Bustard fatality was encountered in association with pylon infrastructure associated with a newly developed wind-farm. Visibility devices must be deployed on new infrastructure developments since overhead cables are a major source of mortality for cranes and bustards, as abundantly illustrated by researchers and conservation organisations (Boshoff et al. 2011, Jenkins et al. 2010, Shaw et al. 2010). Generally, though, given the vast spaces that the Karoo encompasses, it is likely that even large-scale developments (mining, solar energy infrastructure), while locally damaging, will have little impact on overall ecological functioning and integrity for some time to come. However, we need to be aware of long-term cumulative effects of development.

The wing of Ludwig's Bustard recovered from under a powerline (note wind turbines in the background).

Farming

Most of the Karoo land is owned by stock farmers, farming mostly sheep varieties. Given that sheep stock farming is geared towards maintaining vegetation biomass and relies heavily on rangeland (veld) in good condition, the farming community of the Karoo are natural allies when it comes to bird conservation. With the exception of Martial Eagles, Verreaux's Eagle and Pied Crow, which may attack young lambs, there is little conflict between birds and stock farmers.

Overall, landowners were extremely welcoming, hospitable, tolerant, and interested in the bird surveys and the BioGaps project. Certainly, concerns over fracking are a rallying cry shared between both conservationists and landowners reliant on livestock for an income. Further shared concerns include uranium mining: opposition to open cast mining by local farmer action groups saw the withdrawal of at least one proposed operation in the area. Further landowner concerns that could be of interest are those regarding impact on infrastructure, especially mobile phone communication of the SKA and Meerkat radio-telescope arrays. There was also an element of annoyance at mining companies using large transport truck to carry heavy loads from inland mines to the coast, which results in rapid deterioration in road conditions.

That said, certain management practises are cause for concern. Highest priority of these is the use of poison, used for the control of recognised livestock predators. Poison has a devastating effect on a range of target and non-target species, including endangered species (Santangeli et al. 2017). Vultures, raptors and corvids would all be influenced by this practise. Intentional poisoning of birds like Blue Crane is unacceptable: this has been identified as a threat to this species in the Karoo (Gibbons 2011).

The Karoo is criss-crossed by thousands of kilometres of a variety of fences, used traditionally for controlling movement of livestock, and more recently with more of a focus on movement of problem animals. Fences impact birds in a variety of ways, causing direct mortality through snagging on barbed wire; snaring and snarling (when limbs become entangled loose strand wire); direct impact (strand fences through wetlands pose a large threat to low flying birds); and barriers to terrestrial birds (Secretarybirds and Korhaan). There are several methods for reducing minimising the unintended impacts of fences on birdlife, which are summarised in this BirdLife South Africa information pamphlet:

http://www.birdlife.org.za/images/IBA/Brochures/Fences_Birds.pdf

These include: removing non-essential fences; replacing non-essential barbed wire with smooth wire; maintaining fences to re-tension loose wires; increase fence visibility with flappers etc (this also helps prevent Springbok and other game running into fences); and consider the needs of terrestrial birds when placing vermin and game fences, as this will restrict bird movement.

The increasing use of electric fences for jackal control poses a threat to tortoises, but almost certainly are less of a problem for birds. The impact of fences has not yet been properly quantified: however, even a very low resulting injury or fatality rate could result in impacts to local populations simply due to the extraordinary quantity of these fences deployed across the Karoo for livestock management. This is certainly an avenue for further research given the unknowns: but a very large amount of intensive field surveys will certainly make this an unattractive research avenue for traditional university-based academics

Shale gas exploration (Fracking)

The Karoo Biogaps study was initiated to address biodiversity information gaps across this study region, the study area which is delimited by shale-gas extraction concessions. 52% of the Nama-Karoo and 10% of the Succulent Karoo biomes fall within potential concessions (Todd et al. 2016). At least one study on the impact of shale-gas extraction has identified an impact of this activity on bird communities: Farwell et al. (2016) suggest that shale gas development has the potential to fragment regional forests and alter avian communities. During this survey, no extractive activity related to 'fracking' was observed. An overview of the potential impacts on biodiversity and avifauna has been conducted: (Holness et al. 2016), which suggests that under the Big Gas scenario, habitat loss at the landscape scale of as much as 15% could result from wellpads alone for Karoo Long-billed Lark, Karoo Chat and Rufous-eared Warbler. Taking additional habitat loss and disturbance along roads into account, it is not unreasonable to expect declines of as much as 20% in the abundance of the above species. Increased road networks and traffic will likely also have deleterious effects on birds.

The following statement from Holness et al. (2016) should be noted:

"Another hazard to birds is likely to be posed by the ***water produced from shale gas drilling operations****. In fact, for many birds, this* ***may be the major hazard connected with well sites****, and is the most documented aspect of the problems associated with gas and oil wells. Pits or sludge dams constructed near well sites to hold produced water may be lethal to birds. Open water is a limited resource in the Karoo, but a number of nomadic bird species utilise ephemeral ponds for foraging and breeding. While it is not likely that birds would use ponds immediately adjacent to active drilling activities on wellpads, there may be negative impacts from spills and there is also the possibility that ponds are left in place during the production phase when disturbance would be lower and at such time there would be a strong possibility that birds will land on the water, and species such as swifts and swallows (and bats), that drink on the wing by flying across ponds, will attempt to land or to drink. The use of mechanical birds (that look like raptors) perched on the fence surrounding the ponds may be effective deterrents*."

We identify 30 of 100 of the most commonly encountered species that had presence at a point count significantly positively correlated with the presence of water. These species are all likely to be either attracted by the presence of water in the landscape (and are thus especially vulnerable to the presence of potentially contaminated water that will be a feature of shale gas exploration) or use habitat closely tied to water presence (e.g. Namaqua Warbler).

In addition to the above modelling, a species trait-based analysis of life-history traits was conducted on the main avifaunal community. According to this analysis, 40% of >200 species associated with the Karoo are directly or indirectly reliant on water or associated habitat. This is because some interaction between species and water are subtle: for instance, swallows frequently use mud for nest construction; several species roost in, on or near water or water associated habitats (e.g. Phragmites reedbeds), or may be reliant on insect biota that thrives in aquatic environments. Certainly, shale-gas exploration in this arid environment spells bad news for biodiversity and especially birds given our modelling shows water to be an important predictor of species richness and abundance for many species.

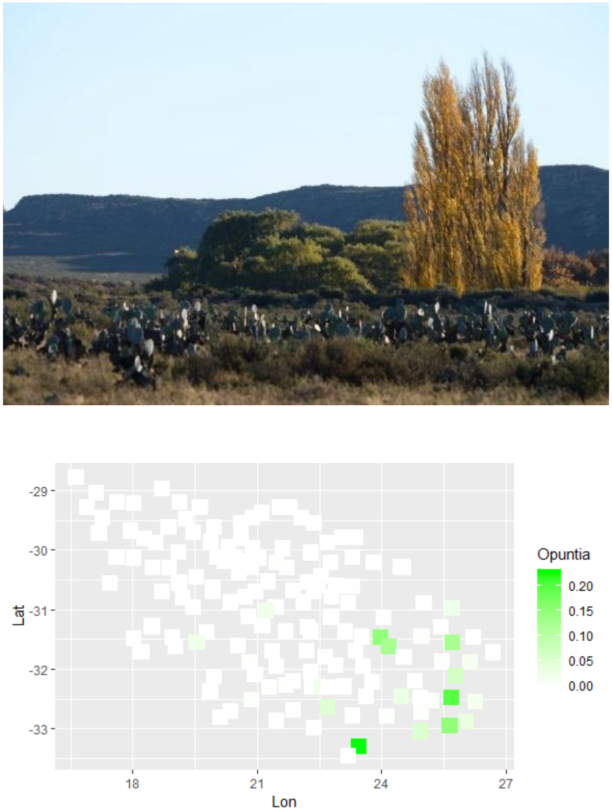
Alien vegetation

During surveys, we made note of the following alien invasive species or plant groups: cactus family (but especially *Opuntia indica* (prickly pear)), *Prosopis glandulosa* or *Prosopis velutina* (Fabaceae, also known as mesquite); *Tamarix ramosissima* (salt cedar or pink tamarisk). Of these, tamarisk was recorded at only one location, although under reporting may have been confounded with its superficial appearance to the indigenous *Tamarix usneoides* (wild tamarisk), where differences are only clear during the flowering season when the pink flowers of the pink tamarisk clearly differentiate this species from wild tamarisk.

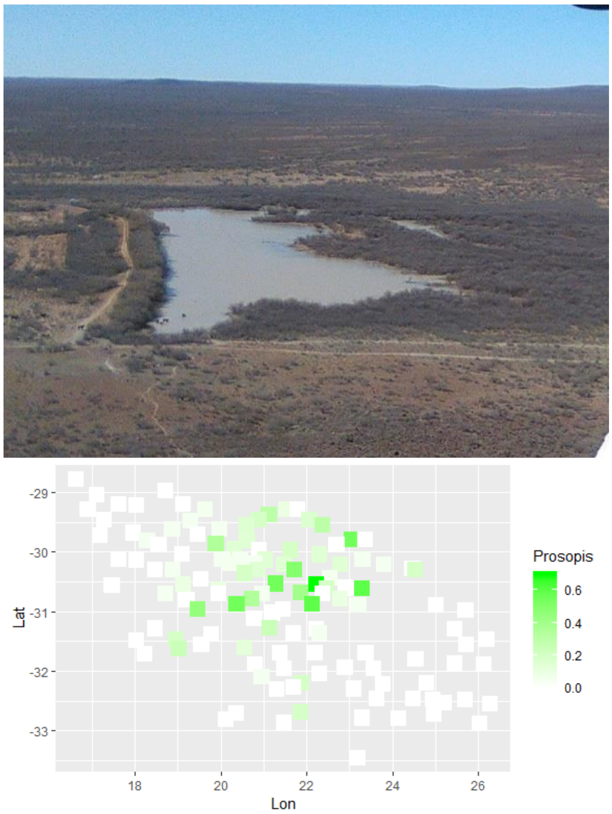
Above: Wild tamarisk (native)
Left: Pink tamarisk (alien)
images courtesy of pza.sanbi.org

On the other hand, prickly pear and mesquite were more frequently encountered, with prickly pear common in the south-eastern Karoo, especially where the Karoo intergrades into Albany Thicket habitat types. This species is frequently encountered around settlements, due to its edible fruit, but also anywhere in the landscape where seeds are dispersed by a variety of fruit eating animals or people (Dean and Milton 2000). Jointed cactus was also observed frequently in this region. A variety of biological control measures have been introduced to slow the spread of *Opuntia* species, but manual removal of dense thickets may still be required in some cases.

By contrast, *Prosopis* was most dominant in the Bushmanland region. It is possible it was under reported from the south and eastern Karoo during our survey where it co-occurs with acacia. *Prosopis* can form very large trees, and the seed pods are edible for livestock and thus seeds can be quickly dispersed through the landscape by goats or sheep. The trees are used by Sociable Weavers for making nests in otherwise tree-less landscapes, and were positively associated with species presence for several species in this survey. However, they can form dense stands and impenetrable thickets, totally transforming dwarf shrub landscape. There are several agriculturally driven landcare projects to assist farmers with dealing with Prosopis, but the fecundity and extent of this species means it will be a feature of the Karoo landscape for aeons to come. Comparisons of acacia and *Prosopis* dominated habitats suggest bird foraging guilds may respond differently to these vegetation types (Dean et al. 2002).



Prickly pear distribution: top shows commonly observed fields of cultivated prickly pear

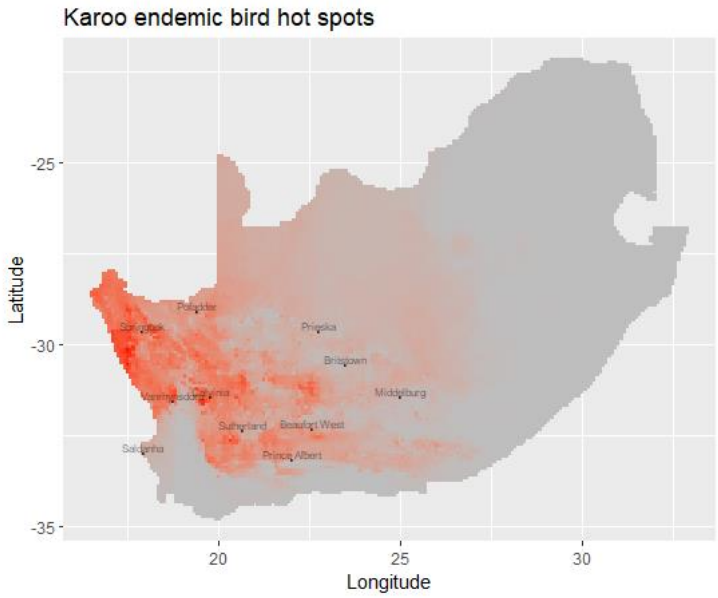


Prosopis distribution: top image shows infestation around a dam north of Carnarvon

Climate Change

Observations and projections for warming across southern Africa's arid zone are alarming (Kruger and Sekele 2013). While many of the resident birds are physiologically and behaviourally adapted to dealing with short periods of extreme temperatures, prolonged periods of abnormal temperatures will hamper birds provisioning rates, foraging, compromise nesting activities and ultimately breeding success.

Certainly, what makes the Succulent Karoo special is not just the timing of rainfall, which occurs predominantly in winter, but also its predictability. Thus, the Succulent Karoo and its biota will be adversely impacted not just by the probability of decreasing rainfall (as predicted by climate change models), but also if rainfall becomes more erratic in the future. The affiliation of most of the Karoo endemic bird species seems to be tied somewhat to this predictable rainfall: and as such climate change poses a serious future threat to the avifauna of the Karoo.



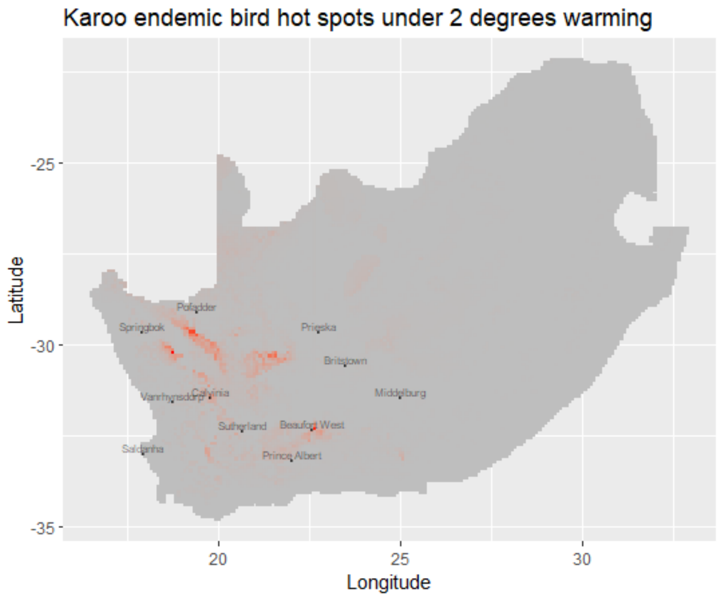
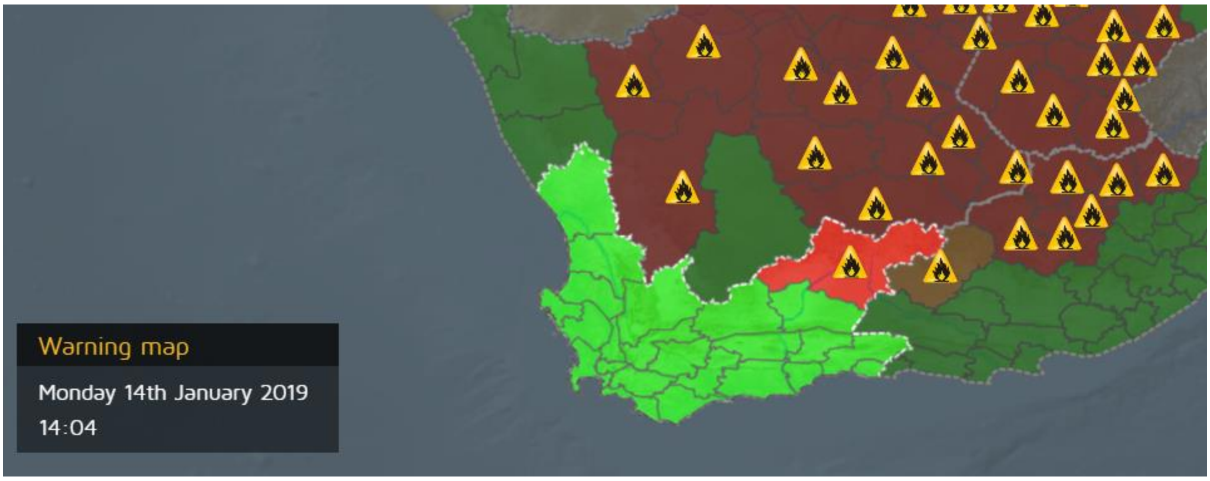


Figure 36: Number of Karoo endemic birds predicted to be observed at a point currently (top), and with a 2 degree increase in mean annual temperature (below). Models were created using a random forest machine learning method using BioClim variables, together with Latitude and Longitude as predictor variables.

Other threats

Fire

In the Nama Karoo, where grass becomes an increasingly dominant component of the vegetation cover, fire management needs careful thought. There is a lot of concern regarding fires, since they can cause loss of life, livestock and infrastructure, and negligence in terms of fire management can result in litigation. With dry conditions accompanied by strong winds, fire can quickly get out of control. However, for grass dominated landscapes, fire is part of the ecological functioning of the landscape: it helps control bush encroachment and rejuvenates moribund veld (du Toit et al. 2015). For birds, unseasonal (spring or early summer) fires can threaten birds that are nesting, or large terrestrial birds (cranes, korhaans), especially very young birds that have limited or no flying abilities.



Agricultural land conversion

Large-scale land conversion for agricultural purposes is normally observed in the Karoo in association with low-lying areas with access to irrigation, where the land is used for growing of pasture crops e.g. lucerne/alfalfa, although increasingly also seed crops e.g. onions; but also for the creation of orchards in some regions. This practise involves complete conversion of natural habitat to managed habitat, with major implications for vegetation. However, especially in the case of pasture crops, these areas are also often very productive in terms of bird species richness and biomass: African Pipit, Red-capped Lark, Egyptian Goose, Spur-winged Goose, South African Shelduck and, occasionally, Blue Crane are associated with these habitats.

Pesticides

Intensive agriculture, especially for fruit, can often involve intensive insecticide spraying regimes. Impacts of pesticide can use can extend far beyond the zone of application, especially for river ecosystems. However, in the arid Karoo regions, agricultural practises that require intensive pesticide use are few and far between, restricted to the fruit growing regions associated with the Orange River to the north and east, and Olifants River to the south, and Fish River to the south east.

Erosion and desertification

Given the arid nature of the Karoo landscape, with low vegetation cover and biomass, erosion and desertification have been hot topics for decades. The number of hectares required per LSU (Liverstock

Unit) is upwards of 40, but over 100 for regions like the Tankwa and Richtersveld. Overstocking and artificially maintaining livestock through water provision during drought periods results in devastating consequences for land condition, the ‘downward spiral’ of loss of vegetation, leading to loss of soil, leading to poor recovery of vegetation.

There is much information available on livestock ecological best practise e.g.
http://www.azef.co.za/pdf/Grazing_Guidelines_Draft.pdf

Plastic and other pollution

The problem of poor recycling infrastructure, waste management and plastic pollution has received much media attention. This is a big problem across South Africa, and especially so around the small towns of the Karoo where municipal dumps are easily identified by the plastic distributed by strong winds in the surrounding landscape. Most farmsteads burn all their rubbish, which may have environmental consequences especially regarding disposal of environmentally hazardous waste like batteries. Plastic adds colour to road verges along main roads throughout the year, unlike wildflowers which do so sporadically and for only a few months at a time at most.

Knowledge gaps and future research opportunities

While our wealth of South African birding literature may give the impression that all is known about our birds, this is certainly not the case, and a lack of even basic biological information is still lacking for many Karoo bird species. Certainly, even our understanding what a species is seems to be a continued matter of debate and is a long way from being resolved. Several species need targeted research programs to resolve taxonomical species, ideally with widespread genetic sampling. Species or species groups that need more attention include Cape vs Eastern Clapper Lark (the contact zone between these in the Karoo is currently biologically meaningless); the Barlow/Karoo Lark complex; the entire Long-billed Lark complex; Black-headed vs Damara Canary: to what degree does Damara occur in South Africa? There is very little published on most of the Karoo endemic species. Sclater's Lark and Cinnamon-breasted Warbler are especially under studied, with little information on breeding or life-history. In addition, restricted occurrence of Cinnamon-breasted Warbler to rocky outcrops suggests the species may well be a candidate species to examine effects of isolation e.g. island biogeography. The ecological conditions related to nomadism could also be further explored for most species, especially the role of rainfall and vegetation condition.

A young Black-headed Canary can look a lot like a Damara Canary when in active moult. Damara Canary have a distinct white eye-brow

Funding and acknowledgements

This research has been made possible thanks to a donation from Gaynor Rupert to BirdLife South Africa. AL wishes to thank Richard Dean for his time, insights and comments. Domitilla Raimondi of SANBI is thanked for the invitation to become part of the SANBI Karoo BioGaps project. Gigi Laidler is thanked for all her groundwork. Campbell Fleming is thanked for assistance during surveys during 2017, and Eric Herrmann for hard work in the field in 2018. Thanks to Adrian Craig, Salome Willemse, and Stefan Theron for assistance with atlassing efforts. The many landowner who allowed us access to their land and provided coffee and conversation are especially thanked, as are the several landowners who facilitated our surveys by offering a place to stay: Ryan Black and family, Hennie Visagie, Tim Hobson, Willie Jordaan, Andre Theron and family, Okkie and Lena Wiehaan, Klaas Louw, Francois van de Merwe, Aletta and Japie Folscher, Gideon and Fransie Hoon.

References

Abdu S, Lee ATK, Cunningham SJ. 2018. The presence of artificial water points structures an arid-zone avian community over small spatial scales. *Ostrich* 89: 339-346.

Archer S. 2000. Technology and ecology in the Karoo: a century of windmills, wire and changing farming practice. *Journal of Southern African Studies* 26: 675-696.

Barton K 2011. MuMIn: Multi-model inference. R package version 1.12.1. Vienna, Austria: R Foundation for Statistical Computing. See http://CRAN. R-project. org/package= MuMIn.

Boshoff AF, Minnie JC, Tambling CJ, Michael MD. 2011. The impact of power line-related mortality on the Cape Vulture Gyps coprotheres in a part of its range, with an emphasis on electrocution. *Bird Conservation International* 21: 311-327.

Buckland ST, Anderson DR, Burnham KP, Laake JL. 2005. Distance Sampling. *Encyclopedia of Biostatistics*: John Wiley & Sons, Ltd.

Child MF, Cumming GS, Amano T. 2009. Assessing the broad-scale impact of agriculturally transformed and protected area landscapes on avian taxonomic and functional richness. *Biological Conservation* 142: 2593-2601.

Cunningham S, Madden C, Barnard P, Amar A. 2016. Electric crows: powerlines, climate change and the emergence of a native invader. *Diversity and Distributions* 22: 17-29.

Cunningham SJ, Kruger AC, Nxumalo MP, Hockey PA. 2013a. Identifying Biologically Meaningful Hot-Weather Events Using Threshold Temperatures That Affect Life-History. *PLoS ONE* 8: e82492.

Cunningham SJ, Martin RO, Hojem CL, Hockey PA. 2013b. Temperatures in excess of critical thresholds threaten nestling growth and survival in a rapidly-warming arid savanna: a study of common fiscals. *PLoS ONE* 8: e74613.

Dean W, Anderson M, Milton S, Anderson T. 2002. Avian assemblages in native *Acacia* and alien *Prosopis* drainage line woodland in the Kalahari, South Africa. *Journal of Arid Environments* 51: 1-19.

Dean W, Milton S. 2000. Directed dispersal of *Opuntia* species in the Karoo, South Africa: are crows the responsible agents? *Journal of Arid Environments* 45: 305-314.

Dean WRJ. 1995. Where birds are rare or fill the air: The protection of tiie endemic and the nomadic avifaunas of the Karoo. PhD, University of Cape Town, Cape Town.

Dean WRJ, Milton SJ (eds). 1999. *The Karoo: Ecological patterns and processes*. Cambridge, UK: Cambridge University Press.

Desmet PG, Cowling RM. 1999. The climate of the Karoo - a functional approach. In: Dean WRJ, Milton SJ editors. *The Karoo: Ecological patterns and processes*. Cambridge, UK: Cambridge University Press. p. 3-16.

du Plessis KL, Martin RO, Hockey PA, Cunningham SJ, Ridley AR. 2012. The costs of keeping cool in a warming world: implications of high temperatures for foraging, thermoregulation and body condition of an arid-zone bird. *Global Change Biology* 18: 3063-3070.

du Toit JCO, van den Berg L, O'Connor TG. 2015. Fire effects on vegetation in a grassy dwarf shrubland at a site in the eastern Karoo, South Africa. *African Journal of Range & Forage Science* 32: 13-20.

Fahrig L, Rytwinski T. 2009. Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and society* 14.

Farwell LS, Wood PB, Sheehan J, George GA. 2016. Shale gas development effects on the songbird community in a central Appalachian forest. *Biological Conservation* 201: 78-91.

Gibbons B. 2011. Recorded Blue Crane *Anthropoides paradiseus* mortalities from 2005 to 2009 in the Karoo. *Indwa* 9: 41-43.

Holness S, Driver A, Todd S, Snaddon K, Hamer M, Raimondo D, Daniels F, Alexander G, Bazelet C, Bills R, *et al.* 2016. Biodiversity and Ecological Impacts: Landscape Processes, Ecosystems and Species. In: Scholes R, Lochner P, Schreiner G, Snyman-Van der Walt L, de Jager M editors. *Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks*. Pretoria, South Africa. Available at http://seasgd.csir.co.za/scientific-assessment-chapters/: CSIR. p. 7-21.

Huntley B, Altwegg R, Barnard P, Collingham YC, Hole DG. 2012. Modelling relationships between species spatial abundance patterns and climate. *Global Ecology and Biogeography* 21: 668-681.
Huston M. 1979. A general hypothesis of species diversity. *The American Naturalist* 113: 81-101.
Jenkins AR, Smallie JJ, Diamond M. 2010. Avian collisions with power lines: a global review of causes and mitigation with a South African perspective. *Bird Conservation International* 20: 263-278.
Kamp J, Oppel S, Heldbjerg H, Nyegaard T, Donald PF. 2016. Unstructured citizen science data fail to detect long-term population declines of common birds in Denmark. *Diversity and Distributions* 22: 1024-1035.
Kruger AC, Sekele SS. 2013. Trends in extreme temperature indices in South Africa: 1962–2009. *International journal of climatology* 33: 661-676.
Kuznetsova A, Brockhoff PB, Christensen RHB. 2017. lmerTest package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software* 82: 1-26.
Lee AT, Barnard P, Hockey PA. 2015. Population metrics for fynbos birds, South Africa: densities, and detection and capture rates from a Mediterranean-type ecosystem. *Ostrich*: 1-9.
Lee ATK, Altwegg R, Barnard P. 2017a. Estimating conservation metrics from atlas data: the case of southern African endemic birds. *Bird Conservation International*: 1-14.
Lee ATK, Barnard P. 2015. Spatial and temporal patterns of insect-order activity patterns in the fynbos, South Africa. *Journal of Entomology and Zoology Studies* 3: 95-102.
Lee ATK, Barnard P. 2017. How well do bird atlas reporting rates reflect bird densities? Correlates of detection from the Fynbos biome, South Africa, with applications for population estimation. *Ostrich*.
Lee ATK, Fleming C, Wright DR. 2018. Modelling bird atlas reporting rate as a function of density in the southern Karoo, South Africa. *Ostrich* 89: 363-372.
Lee ATK, Wright D, Barnard P. 2017b. Hot bird drinking patterns: drivers of water visitation in a fynbos bird community. *African Journal of Ecology* 55: 541-553.
Mangnall MJ, Crowe TM. 2003. The effects of agriculture on farmland bird assemblages on the Agulhas Plain, Western Cape, South Africa. *African Journal of Ecology* 41: 266-276.
McKechnie AE, Wolf BO. 2010. Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. *Biology Letters* 6: 253-256.
Miller DL 2017. Distance: Distance Sampling Detection Function and Abundance Estimation. R package version 0.9.7. https://CRAN.R-project.org/package=Distance.
Mucina L, Rutherford MC. 2006. *The vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute.
O'Connor TG, Puttick JR, Hoffman MT. 2014. Bush encroachment in southern Africa: changes and causes. *African Journal of Range & Forage Science* 31: 67-88.
Pebesma E. 2018. Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal, https://journal.r-project.org/archive/2018/RJ-2018-009/*.
Rheindt FE. 2003. The impact of roads on birds: does song frequency play a role in determining susceptibility to noise pollution? *Journal für Ornithologie* 144: 295-306.
Santangeli A, Arkumarev V, Komen L, Bridgeford P, Kolberg H. 2017. Unearthing poison use and consequent anecdotal vulture mortalities in Namibia's commercial farmland – implications for conservation. *Ostrich* 88: 147-154.
Shaw JM, Jenkins AR, Allan DG, Ryan PG. 2015. Population size and trends of Ludwig's Bustard Neotis ludwigii and other large terrestrial birds in the Karoo, South Africa. *Bird Conservation International* FirstView: 1-18.
Shaw JM, Jenkins AR, Ryan PG, Smallie JJ. 2010. A preliminary survey of avian mortality on power lines in the Overberg, South Africa. *Ostrich* 81: 109-113.
Szabo JK, Fuller RA, Possingham HP. 2012. A comparison of estimates of relative abundance from a weakly structured mass-participation bird atlas survey and a robustly designed monitoring scheme. *Ibis* 154: 468-479.

Tews J, Brose U, Grimm V, Tielbörger K, Wichmann M, Schwager M, Jeltsch F. 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography* 31: 79-92.
Todd S, Hoffman MT, Henschel J, Cardoso A, Brooks M, Underhill L. 2016. Chapter 14. The potential impacts of fracking on biodiversity of the Karoo Basin, South Africa. In: Glazeweski J, Esterhuyse S editors. *Hydraulic fracturing in the Karoo: Critical legal and environmental perspectives*: Juta and company. p. 278-301.
Underhill LG. 2016a. Bibliography: Research papers and postgraduate theses which have been largely dependent on data from the Southern African Bird Atlas Projects. *Biodiversity Observations* 7: 1-13.
Underhill LG. 2016b. The fundamentals of the SABAP2 protocol. *Biodiversity Observations* 8: 1-12.
Van Rensburg B, Chown S, Gaston K. 2002. Species richness, environmental correlates, and spatial scale: a test using South African birds. *The American Naturalist* 159: 566-577.
Vernon CJ. 1999. Biogeography, endemism and diversity of animals in the karoo. In: Dean WRJ, Milton SJ editors. *The Karoo: Ecological patterns and processes*. Cambridge, UK: Cambridge University Press. p. 57-86.
Wright MN, Ziegler A. 2015. Ranger: a fast implementation of random forests for high dimensional data in C++ and R. *Journal of Statistical Software* 77: 1-17.

Appendices

Appendix Table 1: Species, numbers of groups encountered (N), average group size with standard deviation (sd), and maximum group size (max). Names follow IOC 8.2 convention. Species are ranked from most common to least commonly encountered (descending N).

Common_name	Latin_name	N	Mean gs	sd	max
Lark-like Bunting	*Emberiza impetuani*	1205	2.64	5.27	123
Rufous-eared Warbler	*Malcorus pectoralis*	550	1.37	0.56	3
Grey-backed Sparrow-Lark	*Eremopterix verticalis*	513	2.57	2.67	38
Karoo Scrub Robin	*Cercotrichas coryphoeus*	498	1.49	0.56	4
Cape Sparrow	*Passer melanurus*	433	3.05	6.23	100
Pied Crow	*Corvus albus*	432	1.97	2.28	42
Grey-backed Cisticola	*Cisticola subruficapilla*	420	1.45	0.60	4
Spike-heeled Lark	*Chersomanes albofasciata*	418	2.17	1.06	6
Karoo Prinia	*Prinia maculosa*	386	1.52	0.65	5
Cape Bunting	*Emberiza capensis*	380	1.43	0.59	5
Namaqua Sandgrouse	*Pterocles namaqua*	366	4.58	8.38	100
Karoo Long-billed Lark	*Certhilauda subcoronata*	337	1.35	0.53	4
Sabota Lark	*Calendulauda sabota*	320	1.23	0.87	11
Ring-necked Dove	*Streptopelia capicola*	305	2.69	8.25	90
Karoo Chat	*Emarginata schlegelii*	297	1.25	0.45	3
Bokmakierie	*Telophorus zeylonus*	294	1.47	0.55	4
Large-billed Lark	*Galerida magnirostris*	294	1.38	0.58	4
White-throated Canary	*Crithagra albogularis*	269	1.84	1.13	8
Common Fiscal (pre-split)	*Lanius collaris*	251	1.07	0.25	2
Karoo Lark	*Calendulauda albescens*	240	1.32	0.57	4
Eastern Clapper Lark	*Mirafra fasciolata*	236	1.48	0.67	6
Chestnut-vented Warbler	*Sylvia subcoerulea*	229	1.31	0.57	4
Black-eared Sparrow-Lark	*Eremopterix australis*	223	2.04	1.60	11
Chat Flycatcher	*Melaenornis infuscatus*	222	1.26	0.48	3
Yellow-bellied Eremomela	*Eremomela icteropygialis*	201	1.36	0.50	3
Yellow Canary	*Crithagra flaviventris*	200	2.52	4.24	50
Familiar Chat	*Oenanthe familiaris*	192	1.32	0.49	3
Ant-eating Chat	*Myrmecocichla formicivora*	184	1.70	0.96	7
Acacia Pied Barbet	*Tricholaema leucomelas*	183	1.18	0.39	2
Tractrac Chat	*Emarginata tractrac*	183	1.40	0.58	4
Karoo Korhaan	*Eupodotis vigorsii*	182	2.09	0.72	5
Layard's Warbler	*Sylvia layardi*	178	1.34	0.51	3
Northern Black Korhaan	*Afrotis afraoides*	169	1.25	0.58	4
African Red-eyed Bulbul	*Pycnonotus nigricans*	150	1.90	0.79	5
Southern Masked Weaver	*Ploceus velatus*	144	4.05	10.62	100
Dusky Sunbird	*Cinnyris fuscus*	138	1.31	0.60	4
Rock Martin	*Ptyonoprogne fuligula*	132	1.61	0.84	6
Black-chested Prinia	*Prinia flavicans*	126	1.37	0.49	2
Cape Long-billed Lark	*Certhilauda curvirostris*	119	1.21	0.44	3
Stark's Lark	*Spizocorys starki*	117	1.64	0.84	6

Grey Tit	*Melaniparus afer*	109	1.46	0.63	3
Pale Chanting Goshawk	*Melierax canorus*	108	1.05	0.21	2
Mountain Wheatear	*Myrmecocichla monticola*	107	1.25	0.50	3
Red Lark	*Calendulauda burra*	104	1.23	0.45	3
Ludwig's Bustard	*Neotis ludwigii*	96	2.26	1.97	11
Malachite Sunbird	*Nectarinia famosa*	96	1.25	0.58	4
Pririt Batis	*Batis pririt*	96	1.50	0.51	2
Namaqua Dove	*Oena capensis*	94	1.86	1.55	12
Southern Double-collared Sunbird	*Cinnyris chalybeus*	92	1.49	0.69	4
Red-capped Lark	*Calandrella cinerea*	88	1.95	2.32	20
Sickle-winged Chat	*Emarginata sinuata*	88	1.60	0.68	4
Speckled Pigeon	*Columba guinea*	88	5.17	8.29	48
Long-billed Crombec	*Sylvietta rufescens*	80	1.23	0.42	2
Cape Robin-Chat	*Cossypha caffra*	76	1.14	0.35	2
Neddicky	*Cisticola fulvicapilla*	74	1.38	0.75	4
Fairy Flycatcher	*Stenostira scita*	73	1.32	0.52	3
Black-headed Canary	*Serinus alario*	72	3.33	9.36	80
White-necked Raven	*Corvus albicollis*	71	2.01	1.23	10
Pied Starling	*Lamprotornis bicolor*	70	8.59	10.43	55
African Pipit	*Anthus cinnamomeus*	69	1.43	0.59	4
Laughing Dove	*Spilopelia senegalensis*	66	1.85	1.22	6
Red-faced Mousebird	*Urocolius indicus*	66	5.87	4.02	20
Sociable Weaver	*Philetairus socius*	62	14.17	17.41	85
Cape Wagtail	*Motacilla capensis*	61	1.81	1.73	12
Capped Wheatear	*Oenanthe pileata*	61	1.13	0.34	2
Fiscal Flycatcher	*Melaenornis silens*	61	1.39	0.49	2
Common Quail	*Coturnix coturnix*	60	1.60	0.50	2
White-backed Mousebird	*Colius colius*	60	4.69	8.48	61
Egyptian Goose	*Alopochen aegyptiaca*	57	5.16	11.22	80
Pale-winged Starling	*Onychognathus nabouroup*	57	2.89	1.78	10
African Stonechat	*Saxicola torquatus*	56	1.35	0.48	2
South African Shelduck	*Tadorna cana*	54	7.80	35.66	264
Jackal Buzzard	*Buteo rufofuscus*	52	1.10	0.30	2
Karoo Eremomela	*Eremomela gregalis*	50	2.17	1.38	6
African Rock Pipit	*Anthus crenatus*	49	1.28	0.46	2
Long-billed Pipit	*Anthus similis*	48	1.46	0.66	4
Hadada Ibis	*Bostrychia hagedash*	44	2.16	1.26	8
Bar-throated Apalis	*Apalis thoracica*	41	1.60	0.97	4
Scaly-feathered Weaver	*Sporopipes squamifrons*	40	3.10	2.20	10
Cape Crow	*Corvus capensis*	39	1.74	1.04	6
Rock Kestrel	*Falco rupicolus*	39	1.13	0.34	2
White-browed Sparrow-Weaver	*Plocepasser mahali*	39	2.29	2.07	10
Greater Striped Swallow	*Cecropis cucullata*	38	2.21	1.04	5
Cape Clapper Lark	*Mirafra apiata*	36	1.33	0.55	3
Cape Weaver	*Ploceus capensis*	36	5.34	7.66	40
Cape White-eye	*Zosterops virens*	36	2.85	2.87	14
Namaqua Warbler	*Phragmacia substriata*	36	1.93	0.47	3

Southern Black Korhaan	*Afrotis afra*	35	1.00	0.00	1
Blue Crane	*Grus paradisea*	34	3.03	4.03	24
Red-headed Finch	*Amadina erythrocephala*	32	3.10	2.36	10
Cape Penduline Tit	*Anthoscopus minutus*	30	2.44	2.00	10
Little Swift	*Apus affinis*	30	4.67	3.43	12
Verreaux's Eagle	*Aquila verreauxii*	30	1.53	0.57	3
Barlow's Lark	*Calendulauda barlowi*	29	1.24	0.54	3
Southern Red Bishop	*Euplectes orix*	28	12.67	18.12	70
Three-banded Plover	*Charadrius tricollaris*	28	1.63	1.24	6
Cinnamon-breasted Warbler	*Euryptila subcinnamomea*	26	1.56	1.65	8
Cape Bulbul	*Pycnonotus capensis*	25	1.72	0.46	2
Cape Starling	*Lamprotornis nitens*	24	2.96	2.65	10
Common Waxbill	*Estrilda astrild*	23	11.90	10.03	30
Greater Kestrel	*Falco rupicoloides*	23	1.30	0.47	2
Red-winged Starling	*Onychognathus morio*	23	7.48	14.47	50
African Hoopoe	*Upupa africana*	22	1.31	0.48	2
Blacksmith Lapwing	*Vanellus armatus*	22	2.73	2.53	11
Grey-winged Francolin	*Scleroptila afra*	22	4.43	3.39	11
House Sparrow	*Passer domesticus*	20	2.47	1.95	8
Red-billed Quelea	*Quelea quelea*	20	52.35	60.70	200
Sombre Greenbul	*Andropadus importunus*	20	1.00	0.00	1
Southern Grey-headed Sparrow	*Passer diffusus*	20	1.88	0.50	3
Double-banded Courser	*Rhinoptilus africanus*	19	1.26	0.56	3
Fork-tailed Drongo	*Dicrurus adsimilis*	19	1.67	0.77	4
Kalahari Scrub Robin	*Cercotrichas paena*	19	1.20	0.41	2
Southern Boubou	*Laniarius ferrugineus*	19	1.80	0.45	2
Cape Spurfowl	*Pternistis capensis*	18	5.80	9.07	22
White-rumped Swift	*Apus caffer*	18	3.83	3.19	12
Cinnamon-breasted Bunting	*Emberiza tahapisi*	17	1.60	0.70	3
Red-eyed Dove	*Streptopelia semitorquata*	17	1.46	0.88	4
Barn Swallow	*Hirundo rustica*	16	3.13	3.32	12
Chinspot Batis	*Batis molitor*	15	2.50	0.71	3
European Bee-eater	*Merops apiaster*	15	4.43	4.24	15
Karoo Thrush	*Turdus smithi*	15	1.54	0.66	3
White-throated Swallow	*Hirundo albigularis*	15	1.67	0.90	4
Alpine Swift	*Tachymarptis melba*	14	9.43	15.47	50
Booted Eagle	*Hieraaetus pennatus*	14	1.00	0.00	1
Brown-throated Martin	*Riparia paludicola*	14	2.50	2.35	10
Black-winged Stilt	*Himantopus himantopus*	13	5.00	5.10	20
Cape Longclaw	*Macronyx capensis*	13	1.56	0.53	2
Cardinal Woodpecker	*Dendropicos fuscescens*	13	1.25	0.50	2
Pearl-breasted Swallow	*Hirundo dimidiata*	13	1.33	0.49	2
Pied Avocet	*Recurvirostra avosetta*	13	3.92	2.87	10
Speckled Mousebird	*Colius striatus*	13	5.23	4.19	15
Yellow-billed Duck	*Anas undulata*	13	3.00	1.86	6
Cloud Cisticola	*Cisticola textrix*	12	1.25	0.50	2
Dark-capped Bulbul	*Pycnonotus tricolor*	12	2.20	0.45	3
Lesser Kestrel	*Falco naumanni*	12	36.58	57.85	200

Ground Woodpecker	*Geocolaptes olivaceus*	11	1.80	0.45	2
Helmeted Guineafowl	*Numida meleagris*	11	20.00	11.56	32
Black-throated Canary	*Crithagra atrogularis*	10	7.90	9.07	30
Cape Canary	*Serinus canicollis*	10	2.67	1.94	6
Fawn-colored Lark	*Calendulauda africanoides*	10	1.00	0.00	1
Cape Teal	*Anas capensis*	9	8.33	15.76	50
Eastern Long-billed Lark	*Certhilauda semitorquata*	9	1.33	0.58	2
Melodious Lark	*Mirafra cheniana*	9	1.25	0.46	2
Rufous-naped Lark	*Mirafra africana*	9	1.00	0.00	1
Sclater's Lark	*Spizocorys sclateri*	9	5.44	9.38	30
South African Cliff Swallow	*Petrochelidon spilodera*	9	3.44	6.25	20
Spur-winged Goose	*Plectropterus gambensis*	9	6.33	8.32	24
Black-headed Oriole	*Oriolus larvatus*	8	1.40	0.55	2
Black Harrier	*Circus maurus*	8	1.13	0.35	2
Brown-hooded Kingfisher	*Halcyon albiventris*	8	1.33	0.58	2
Golden-breasted Bunting	*Emberiza flaviventris*	8	1.29	0.49	2
Levaillant's Cisticola	*Cisticola tinniens*	8	1.25	0.50	2
Pin-tailed Whydah	*Vidua macroura*	8	4.38	3.62	12
Red-knobbed Coot	*Fulica cristata*	8	8.63	9.58	25
Lesser Swamp Warbler	*Acrocephalus gracilirostris*	7	1.00	0.00	1
Red-fronted Tinkerbird	*Pogoniulus pusillus*	7			
Short-toed Rock Thrush	*Monticola brevipes*	7	1.00	0.00	1
African Fish Eagle	*Haliaeetus vocifer*	6	1.33	0.52	2
Common Starling	*Sturnus vulgaris*	6	2.67	1.51	4
Desert Cisticola	*Cisticola aridulus*	6	1.00	0.00	1
Greater Honeyguide	*Indicator indicator*	6	1.00		1
Pygmy Falcon	*Polihierax semitorquatus*	6	1.50	0.55	2
Red-billed Teal	*Anas erythrorhyncha*	6	2.67	1.51	5
Southern Tchagra	*Tchagra tchagra*	6	1.00	0.00	1
Streaky-headed Seedeater	*Crithagra gularis*	6	2.20	1.10	3
Wattled Starling	*Creatophora cinerea*	6	10.00	9.21	23
Yellow-fronted Canary	*Crithagra mozambica*	6	9.83	19.68	50
Black-headed Heron	*Ardea melanocephala*	5	1.40	0.89	3
Burchell's Courser	*Cursorius rufus*	5	2.00	1.00	3
Crowned Lapwing	*Vanellus coronatus*	5	1.67	1.15	3
Martial Eagle	*Polemaetus bellicosus*	5	1.20	0.45	2
Olive Thrush	*Turdus olivaceus*	5	2.00	0.82	3
Spotted Thick-knee	*Burhinus capensis*	5	1.00	0.00	1
Greater Double-collared Sunbird	*Cinnyris afer*	4	1.00	0.00	1
Green Wood Hoopoe	*Phoeniculus purpureus*	4	3.00		3
Kelp Gull	*Larus dominicanus*	4	5.50	3.32	9
Kittlitz's Plover	*Charadrius pecuarius*	4	3.50	1.00	4
Knysna Woodpecker	*Campethera notata*	4			
Kori Bustard	*Ardeotis kori*	4	1.25	0.50	2
Lesser Honeyguide	*Indicator minor*	4	1.00	0.00	1
Little Grebe	*Tachybaptus ruficollis*	4	19.25	21.19	50
Quailfinch	*Ortygospiza atricollis*	4	2.25	0.96	3
Secretarybird	*Sagittarius serpentarius*	4	1.25	0.50	2

Tambourine Dove	*Turtur tympanistria*	4			
Wailing Cisticola	*Cisticola lais*	4	1.00	0.00	1
White-browed Robin-Chat	*Cossypha heuglini*	4	1.00	0.00	1
African Harrier-Hawk	*Polyboroides typus*	3	1.00	0.00	1
African Sacred Ibis	*Threskiornis aethiopicus*	3	9.00	9.85	20
Black-winged Kite	*Elanus caeruleus*	3	1.00	0.00	1
Brimstone Canary	*Crithagra sulphurata*	3	2.00		2
Common Scimitarbill	*Rhinopomastus cyanomelas*	3	1.00		1
Diederik Cuckoo	*Chrysococcyx caprius*	3	1.00	0.00	1
Gabar Goshawk	*Micronisus gabar*	3	1.33	0.58	2
Greater Flamingo	*Phoenicopterus roseus*	3	77.67	64.86	120
Grey Heron	*Ardea cinerea*	3	1.00	0.00	1
Lanner Falcon	*Falco biarmicus*	3	1.00	0.00	1
Orange River White-eye	*Zosterops pallidus*	3	2.33	2.31	5
Pied Kingfisher	*Ceryle rudis*	3	1.00	0.00	1
Pink-billed Lark	*Spizocorys conirostris*	3	4.67	4.62	10
Plain-backed Pipit	*Anthus leucophrys*	3	1.33	0.58	2
Red-billed Firefinch	*Lagonosticta senegala*	3	4.33	4.93	10
Red-crested Korhaan	*Lophotis ruficrista*	3	1.00		1
Southern Black Tit	*Melaniparus niger*	3	1.00		1
Spotted Eagle-Owl	*Bubo africanus*	3	1.00	0.00	1
African Black Duck	*Anas sparsa*	2	2.00	0.00	2
African Palm Swift	*Cypsiurus parvus*	2	1.50	0.71	2
Amethyst Sunbird	*Chalcomitra amethystina*	2	1.00	0.00	1
Ashy Tit	*Melaniparus cinerascens*	2	1.50	0.71	2
Black-chested Snake Eagle	*Circaetus pectoralis*	2	1.00	0.00	1
Black-collared Barbet	*Lybius torquatus*	2	2.00	1.41	3
Black-necked Grebe	*Podiceps nigricollis*	2	162.50	194.45	300
Cape Batis	*Batis capensis*	2	1.00		1
Cape Grassbird	*Sphenoeacus afer*	2	2.00		2
Cape Shoveler	*Spatula smithii*	2	3.00	1.41	4
Common Moorhen	*Gallinula chloropus*	2	1.00		1
Crested Barbet	*Trachyphonus vaillantii*	2	1.50	0.71	2
Klaas's Cuckoo	*Chrysococcyx klaas*	2	1.00		1
Olive Woodpecker	*Dendropicos griseocephalus*	2	1.00		1
Peregrine Falcon	*Falco peregrinus*	2	1.50	0.71	2
Red-backed Shrike	*Lanius collurio*	2	1.00	0.00	1
Red-throated Wryneck	*Jynx ruficollis*	2			
Reed Cormorant	*Microcarbo africanus*	2	1.50	0.71	2
White-bellied Bustard	*Eupodotis senegalensis*	2	2.50	0.71	3
Yellow-billed Kite	*Milvus aegyptius*	2	1.00	0.00	1
Yellow-throated Petronia	*Gymnoris superciliaris*	2	2.50	0.71	3
Yellow Bishop	*Euplectes capensis*	2	1.00		1
African Dusky Flycatcher	*Muscicapa adusta*	1	1.00		1
African Firefinch	*Lagonosticta rubricata*	1	2.00		2
African Snipe	*Gallinago nigripennis*	1	1.00		1
Black-backed Puffback	*Dryoscopus cubla*	1	1.00		1
Black-crowned Night Heron	*Nycticorax nycticorax*	1	15.00		15

Black Heron	*Egretta ardesiaca*	1	2.00	2
Black Stork	*Ciconia nigra*	1	1.00	1
Cape Rock Thrush	*Monticola rupestris*	1	1.00	1
Common Greenshank	*Tringa nebularia*	1	3.00	3
Great Crested Grebe	*Podiceps cristatus*	1	2.00	2
Grey-headed Gull	*Chroicocephalus cirrocephalus*	1	2.00	2
Hamerkop	*Scopus umbretta*	1	3.00	3
Knysna Turaco	*Tauraco corythaix*	1	1.00	1
Lazy Cisticola	*Cisticola aberrans*	1	1.00	1
Lesser Striped Swallow	*Cecropis abyssinica*	1	2.00	2
Little Rush Warbler	*Bradypterus baboecala*	1		
Little Stint	*Calidris minuta*	1	14.00	14
Maccoa Duck	*Oxyura maccoa*	1	8.00	8
Marsh Sandpiper	*Tringa stagnatilis*	1	1.00	1
Rock Dove	*Columba livia*	1	7.00	7
Scaly-throated Honeyguide	*Indicator variegatus*	1	1.00	1
Southern Pochard	*Netta erythrophthalma*	1	10.00	10
Spotted Flycatcher	*Muscicapa striata*	1	1.00	1
Tawny-flanked Prinia	*Prinia subflava*	1	2.00	2
Water Thick-knee	*Burhinus vermiculatus*	1	2.00	2
Western Cattle Egret	*Bubulcus ibis*	1	1.00	1
White-breasted Cormorant	*Phalacrocorax lucidus*	1	10.00	10
White-fronted Bee-eater	*Merops bullockoides*	1	3.00	3
White Stork	*Ciconia ciconia*	1	2.00	2
Wood Sandpiper	*Tringa glareola*	1	4.00	4

Appendix Table 2: Species identified as having presence positively associated with the presence of water at a point count. This is a subset of the 100 species for which this was examined as a covariate: so is by no means a complete list of species associated with water. Slope coefficients (estimate) together with standard error (se) are provided. Df = number of points with the species used in the analysis. Some species with known associations with water (Three-banded plover) may have non-significant results due to low encounter rates.

Species	**Df**	**estimate**	**se**	**statistic**	**p.value**
Lark-like Bunting	687	1.898	0.295	6.436	0.000
Cape Sparrow	294	1.537	0.253	6.065	0.000
Karoo Prinia	276	0.973	0.320	3.041	0.002
Cape Turtle	123	1.316	0.268	4.902	0.000
White-throated Canary	209	1.425	0.290	4.914	0.000
Chestnut-vented Titbabbler	142	0.662	0.308	2.144	0.032
Yellow Canary	138	1.170	0.264	4.425	0.000
Pied Barbet	74	0.828	0.356	2.326	0.020
Ant-eating Chat	59	1.341	0.433	3.100	0.002
Masked Weaver	86	1.616	0.299	5.407	0.000
Rock Martin	91	0.793	0.341	2.324	0.020
Namaqua Dove	67	1.946	0.337	5.769	0.000
Speckled Pigeon	48	1.553	0.381	4.072	0.000
Black-headed Canary	49	1.257	0.416	3.022	0.003
Pied Starling	19	2.291	0.489	4.683	0.000
Cape Wagtail	38	3.392	0.403	8.407	0.000
Egyptian Goose	9	3.210	0.775	4.141	0.000
South African Shelduck	14	3.518	0.693	5.079	0.000
Hadeda	10	4.068	0.856	4.752	0.000
Namaqua Warbler	19	1.809	0.626	2.892	0.004
Cape Weaver	22	1.363	0.643	2.119	0.034
Three-banded Plover	11	5.318	1.160	4.583	0.000
Red Bishop	18	2.471	0.542	4.560	0.000
Common Waxbill	12	2.326	0.696	3.341	0.001
Sclater's Lark	7	2.530	0.864	2.927	0.003

Appendix 3: Model table results for the best models by AIC predicting Karoo endemic bird presence at a point from habitat and landscape features from logistic regression models. Species are arranged in alphabetical order, and then by coefficients as determined by the lowest p values. P values significant at 0.01 are indicated in bold.

Species	***n***	***coefficient***	***estimate***	***std.error***	***statistic***	***p.value***
Barlow's Lark	16	Intercept	-8.993	2.412	-3.728	**0.000**
		Sand cover	1.292	0.391	3.304	**0.001**
		Grass cover	-4.822	2.051	-2.351	0.019
		Tar Road	2.236	1.035	2.161	0.031
		Green score	-0.939	0.613	-1.533	0.125
		Wind	-0.346	0.262	-1.323	0.186
		Veld.condition Poor condition	-1.265	1.259	-1.004	0.315
		Veld.conditionLight Grazing	0.895	1.165	0.768	0.442
		Veld.conditionMixed	-0.014	1.267	-0.011	0.991
		Veld.conditionHeavily grazed	-18.444	1882.635	-0.010	0.992
		Presence of Prosopis	-18.161	4092.753	-0.004	0.996
Black-eared Sparrowlark	125	flower_pa	1.767	0.230	7.664	**0.000**
		Sand cover	0.772	0.123	6.289	**0.000**
		Grass cover	0.559	0.121	4.605	**0.000**
		Telephone poles	-1.181	0.332	-3.558	**0.000**
		Recent rain	1.005	0.300	3.356	**0.001**
		Temperature	-0.258	0.105	-2.460	0.014
		Veld.conditionLight Grazing	1.815	0.753	2.410	0.016
		Sheep	-0.561	0.254	-2.210	0.027
		Plains	1.432	0.739	1.938	0.053
		Veld.conditionMixed	1.319	0.823	1.603	0.109
		Presence of Prosopis	-0.823	0.553	-1.489	0.136
		Veld.conditionHeavily grazed	0.984	0.760	1.295	0.195
		Ridge/Hilltop	0.573	1.031	0.556	0.578
		Veld.condition Poor condition	-0.162	0.904	-0.179	0.858
		Slope	0.118	0.861	0.138	0.891
		Intercept	-28.218	958.106	-0.029	0.977
		Acacia cover	-72.636	3174.019	-0.023	0.982
		Tar Road	-19.304	6216.670	-0.003	0.998
		Farmhouse	-19.736	9536.841	-0.002	0.998

Species	*n*	*coefficient*	*estimate*	*std.error*	*statistic*	*p.value*
Cape Long-billed Lark	47	Veld.conditionHeavily grazed	-3.255	0.572	-5.691	**0.000**
		Wind	-0.803	0.152	-5.287	**0.000**
		Recent rain	2.878	0.569	5.062	**0.000**
		Veld.condition Poor condition	-3.885	0.804	-4.832	**0.000**
		Veld.conditionLight Grazing	-2.371	0.518	-4.577	**0.000**
		Green score	0.793	0.202	3.918	**0.000**
		Sand cover	0.871	0.244	3.567	**0.000**
		Grass cover	-1.890	0.531	-3.562	**0.000**
		Veld.conditionMixed	-2.214	0.750	-2.950	**0.003**
		Tar Road	1.945	0.835	2.328	0.020
		Telephone poles	-1.710	0.777	-2.200	0.028
		Vegetation height	0.854	0.448	1.905	0.057
		Plains	1.961	1.095	1.791	0.073
		Slope	1.057	1.138	0.929	0.353
		Ridge/Hilltop	0.739	1.519	0.487	0.626
		Intercept	-43.771	2890.223	-0.015	0.988
		Acacia cover	-80.465	7004.988	-0.011	0.991
		Other tree cover	-62.192	7561.885	-0.008	0.993
		Presence of Prosopis	-21.703	11231.185	-0.002	0.998
Cinnamon-breasted Warbler	20	Intercept	-4.859	1.072	-4.532	**0.000**
		Sand cover	-1.182	0.435	-2.720	**0.007**
		Grass cover	-0.934	0.359	-2.599	**0.009**
		Temperature	0.568	0.290	1.959	0.050
		Wind	-0.245	0.180	-1.361	0.173
		Acacia cover	-2.692	2.618	-1.028	0.304
		Ridge/Hilltop	-0.291	0.834	-0.349	0.727
		Slope	0.034	0.703	0.048	0.962
		Plains	-18.688	1745.301	-0.011	0.991
		Telephone poles	-18.280	2751.599	-0.007	0.995
		Recent rain	-19.194	4219.586	-0.005	0.996
Karoo Chat	153	Intercept	-2.750	0.294	-9.366	**0.000**
		Grass cover	-1.218	0.162	-7.522	**0.000**
		Plains	-1.219	0.270	-4.520	**0.000**
		Vegetation height	-0.987	0.299	-3.306	**0.001**
		Ridge/Hilltop	-1.188	0.448	-2.650	**0.008**
		Other tree cover	-1.056	0.453	-2.333	0.020
		Presence of Prosopis	-1.156	0.529	-2.185	0.029
		Acacia cover	-0.660	0.326	-2.025	0.043
		Slope	-0.589	0.293	-2.009	0.045
		Sand cover	-0.166	0.096	-1.729	0.084
		Telephone poles	0.349	0.206	1.694	0.090

Species	***n***	***coefficient***	***estimate***	***std.error***	***statistic***	***p.value***
Karoo Eremomela	44	Grass cover	-1.222	0.303	-4.029	**0.000**
		flower_pa	0.910	0.354	2.570	0.010
		Green score	-0.437	0.195	-2.244	0.025
		Temperature	-0.309	0.162	-1.911	0.056
		Ridge/Hilltop	1.478	0.824	1.794	0.073
		Slope	0.987	0.775	1.274	0.203
		Plains	0.195	0.761	0.257	0.797
		Intercept	-29.431	1650.684	-0.018	0.986
		Acacia cover	-80.384	5468.397	-0.015	0.988
		Presence of Prosopis	-20.512	8227.068	-0.002	0.998
		Water	-20.082	9366.869	-0.002	0.998
Karoo Korhaan	38	Intercept	-4.382	0.299	-14.641	**0.000**
		flower_pa	-1.147	0.455	-2.523	0.012
		Sheep	0.788	0.336	2.344	0.019
		Telephone poles	0.676	0.357	1.892	0.059
		Grass cover	-0.325	0.188	-1.734	0.083
		Vegetation height	-0.494	0.350	-1.412	0.158
		Presence of Prosopis	-1.242	1.027	-1.209	0.227
Karoo Lark	140	Sand cover	0.546	0.220	2.480	0.013
		Farmhouse	-3.152	1.472	-2.142	0.032
		Wind	-0.291	0.141	-2.060	0.039
		Temperature	-0.378	0.196	-1.931	0.053
		Telephone poles	0.686	0.370	1.854	0.064
		Acacia cover	-1.338	0.833	-1.607	0.108
		Recent rain	-1.767	1.208	-1.462	0.144
		Intercept	-22.798	6829.792	-0.003	0.997
Karoo long-billed lark	134	Intercept	-2.512	0.304	-8.253	**0.000**
		Green score	-0.588	0.136	-4.317	**0.000**
		Temperature	-0.311	0.095	-3.287	**0.001**
		Plains	-0.996	0.308	-3.232	**0.001**
		Acacia cover	-0.546	0.223	-2.453	0.014
		Grass cover	-0.256	0.111	-2.314	0.021
		Vegetation height	0.243	0.109	2.229	0.026
		Sheep	-0.378	0.209	-1.805	0.071
		flower_pa	0.325	0.207	1.567	0.117
		Other tree cover	-0.249	0.201	-1.243	0.214
		Ridge/Hilltop	-0.249	0.464	-0.537	0.591
		Slope	0.173	0.331	0.523	0.601
Large-billed Lark	177	Green score	0.471	0.173	2.723	**0.006**
		Ridge/Hilltop	-1.560	0.700	-2.230	0.026
		Slope	-0.870	0.433	-2.009	0.044
		Temperature	-0.247	0.134	-1.842	0.065
		Plains	0.626	0.357	1.755	0.079
		Vegetation height	-0.420	0.244	-1.721	0.085
		Recent rain	1.298	0.769	1.687	0.092
		Tar Road	-1.127	0.673	-1.676	0.094
		Intercept	-20.551	4072.017	-0.005	0.996

Species	n	coefficient	estimate	std.error	statistic	p.value
Namaqua Warbler	19	Intercept	-4.344	0.755	-5.753	**0.000**
		Vegetation height	0.484	0.142	3.403	**0.001**
		Water	1.809	0.626	2.892	**0.004**
		Recent rain	2.196	0.766	2.866	**0.004**
		Plains	-2.324	0.903	-2.574	0.010
		Wind	-0.493	0.201	-2.456	0.014
		Other tree cover	-0.621	0.257	-2.417	0.016
		Acacia cover	0.264	0.143	1.844	0.065
		Farmhouse	1.616	1.022	1.581	0.114
		Slope	-17.577	1301.695	-0.014	0.989
		Ridge/Hilltop	-16.656	2489.641	-0.007	0.995
Red Lark	35	Grass cover	0.861	0.195	4.423	**0.000**
		Sand cover	0.682	0.199	3.429	**0.001**
		Temperature	-0.430	0.194	-2.214	0.027
		flower_pa	0.763	0.368	2.072	0.038
		Wind	0.227	0.118	1.929	0.054
		Veld.conditionHeavily grazed	-1.103	1.198	-0.921	0.357
		Veld.conditionLight Grazing	0.880	1.095	0.804	0.421
		Veld.conditionMixed	-0.627	1.460	-0.429	0.668
		Veld.condition Poor condition	0.249	1.174	0.212	0.832
		Intercept	-27.521	1623.877	-0.017	0.986
		Acacia cover	-71.772	5379.590	-0.013	0.989
Sclater's Lark	7	Water	2.530	0.864	2.927	**0.003**
		Green score	-1.130	0.683	-1.655	0.098
		Intercept	-22.395	1429.150	-0.016	0.987
		Other tree cover	-61.162	5484.841	-0.011	0.991