**Title: How well do bird atlas reporting rates reflect bird densities? Correlates of detection from the Fynbos biome, South Africa, with applications for population estimation.**

TOST-2016-0012.R1

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# **Abstract**

Relationships between true population densities and reporting indices from atlas data are important for the calculation of population sizes, though these relationships are remarkably little-known and likely confounded by issues of detection. We examine issues of detection for a single observer point count survey across the Fynbos biome in South Africa. We created an index of relative abundance comparable to atlas reporting rate and calculated detection coefficients for each species. We explore various models that explain relative abundance as a function of detection covariates e.g. mass, colour, group size, vocal behaviour and density. Density was consistently included across models and the best predictor when used alone in a validation exercise. We then calculated for the citizen science South African Bird Atlas Project2 (SABAP2) mean reporting rates. A model of species’ reporting rates as determined by density for this set of birds suggested the correlation between atlas reporting rates and density estimates was weak, with species capable of using modified habitats exhibiting higher reporting rates than expected from the density estimates. There was a positive correlation between bird density and reporting rates corrected for by species mass. We use this relationship to calculate densities for the Fynbos bird species and compare results to published data.

# **Introduction**

Population estimates are required to ensure robust decisions on the conservation status of any species ([IUCN Standards and Petitions Subcommittee 2014](#_ENREF_19)) and a requirement for conservation or other management plans ([Lebreton and Clobert 1991](#_ENREF_21)). Obtaining population estimates for species with large ranges or for scarce species is often difficult. Furthermore, density estimates or population surveys are often confounded by issues of detectability ([Pollock, et al. 2004](#_ENREF_28), [Rosenstock, et al. 2002](#_ENREF_30)).

Estimation of a species’ population depends on the probability of detection under a particular sampling regime: if only those animals available to be counted are sampled, without taking into account detection function which accounts for the missed portion of the population, then the resulting abundance estimate is only of that population of available animals. Within a set of species there are many variables that may contribute to the variation between abundance estimates that do not use a detection function. It is likely that larger species will be detected more frequently than smaller species; larger groups are more likely to be detected than smaller groups; more vocal species are more likely to be detected than quiet species; and species more tolerant of humans are more likely to be detected than those that flee at larger distances from humans. Within a set of species it may be possible to model the degree to which these factors influence abundance estimates, and so correct for them accordingly in surveys that cannot explicitly account for that proportion of the population unavailable for counting. Summary statistics of relative abundance, e.g. from some bird atlas projects, need to be modified by methods that account for non-detection in order to be more useful.

Large scale-geographical datasets are becoming increasingly common as a result of citizen science projects. Translating population indices from these datasets into population metrics can be difficult ([Dickinson, et al. 2010](#_ENREF_11)). Observational data reflect both the underlying biological process and the observation process ([Williams, et al. 2002](#_ENREF_36)) and resulting population estimates can be imprecise because of the observation process ([Kéry 2011](#_ENREF_20)). Understanding factors leading to observation bias may help improve population estimates from these datasets.

The Southern African Bird Atlas Project (SABAP) is probably Africa’s largest citizen science biodiversity data collection project ([Harrison, et al. 2008](#_ENREF_17)), focusing on distribution and relative abundance of birds in up to six countries of southern Africa. Resulting publications have provided a substantive basis for detailed conservation planning, policy development and management in the region ([e.g. Barnard and Villiers 2012](#_ENREF_2)). Thus far two studies, which have examined how the index of abundance from this atlas (reporting rates) reflects local population abundance, have found that reporting rates were correlated with abundance ([Amar, et al. 2015](#_ENREF_1), [Robertson, et al. 1995](#_ENREF_29)).

Our study aims to explore correlates of detection for a set of birds from the Cape floristic region (Fynbos) in South Africa. The Fynbos is a hotspot renowned for its botanical diversity, and is home to six endemic passerines and one endemic turnicid ([Lee, et al. 2015](#_ENREF_22)). Generally it is considered to have low bird biodiversity ([Péron and Altwegg 2015](#_ENREF_27)), but the endemic species are of conservation concern especially due to threats resulting from alien vegetation encroachment, landscape conversion and climate change ([Lee and Barnard 2015](#_ENREF_23), [Milne 2014](#_ENREF_24)). While many of these species live in hard to access mountain locations, the region has been well covered by atlasing efforts. Through a standardized distance sampling survey undertaken across the region, we have the unique opportunity to compare atlas reporting rates to bird densities accounting for correlates of detection.

In the paper we aim to identify how species’ characteristics and behaviour influence detection rate in a point count survey. We hypothesize that larger, colourful, vocal species more tolerant of human presence and habitat modification will be those reported most frequently. Likewise, more common species, i.e. those occurring at higher densities, should be reported more frequently. We then examine how the citizen science atlas reporting rates correlate with density estimates calculated from the same survey area and use what we have learnt to create a model that allows prediction of bird density and population size from SABAP2 data.

# **Methods**

***Point count survey to determine relative abundance***

A point count survey (survey 1) was conducted by AL across the biome from January to May 2012 (899 points), with 65% repetition of survey effort in the austral winter-spring from August to October. A second survey (survey 2; 125 points repeated monthly) was conducted from January - September 2013 over a smaller area of the Fynbos associated with the Baviaanskloof Nature Reserve, which we use here for model validation. Counts were conducted from daybreak for up to four hours, and from 15:00 until dusk along survey lines between five and ten kilometres long, depending on terrain.

All observations of any group encounters of each species were summed to create an index of relative abundance i.e. the number of groups of each species encountered per survey was recorded, avoiding repeat counting of groups wherever possible. We use this index of relative abundance, rather than the sum of individuals seen, as it parallels reporting rates derived from presence/absence data from SABAP2.

***Covariates of detection***

During each 10 minute count we recorded the following information for each bird group detected: number of individuals (group size); birds detected due to vocalizations as a proportion of all encounters (vocalization score); bird activity from four categories: flying, flying then perching, perching then flying, perched only; from which we calculated the proportion of all flying groups of the total (mobility score); and proportion of birds that flew and perched near the observer of all encounters (tolerance score). This tolerance score will include elements of sentinel behaviour as well as juvenile curiosity or naivety, all of which would potentially make birds more detectable. The mass of each bird was calculated as the mean from records of adult birds ringed in the region by AL, supplemented with information from [Hockey, et al. (2005)](#_ENREF_18). Colour was ranked as 1 (drab), 2 (intermediate plumage, or mostly black and white), or 3 (more than half the bird plumage bright primary colours, with scores for sexually dimorphic species based on the most colourful sex).

The mean vegetation height of each point was calculated using a modified Braun-Blaunquet scale (see Lee & Barnard 2015 for details). For each bird species we calculated a score of preferred vegetation height based on the mean of vegetation height from points where that species was recorded. The survey points were preferentially located in natural habitat, but any landscape modification was noted e.g. agriculture or human settlements. A modified habitat preference score was calculated for each species as a proportion of the total number of encounters in points with modified habitats divided by the total number of encounters. Bird species and detection covariates are listed in supplementary information 1.

***Calculation of bird densities from point counts***

Only encounters with birds that were initially detected as perched during the point count were used to calculate density estimates following the snapshot paradigm suggested by [Buckland, et al. (2005b)](#_ENREF_9). Distance to each perched group was measured in meters using a laser rangefinder. We calculated density estimates using the Distance 6.2 software ([Thomas, et al. 2010](#_ENREF_35)). Densities were calculated for 32 species with >20 encounters using the conventional-distance-sampling engine. Densities were calculated for survey 1 and survey 2 separately to create global density estimates (for the first survey) and local density estimates (for the second survey). We selected the best detection function model from the set consisting of the combinations of suggested key functions and adjustment terms (uniform with cosine or simple polynomial, half-normal with cosine or hermite polynomial and hazard-rate with cosine or simple polynomial) by delta AIC values ([Buckland, et al. 2005a](#_ENREF_8)). We used the size-bias regression method available in the software for group size estimation. Data were generally truncated to exclude the furthest 5 – 10% of observations to improve model fit. We allowed the software to select distance intervals, with the exception of Orange-breasted Sunbird, Greater Double-collared Sunbird and Karoo Scrub-robin where there was evidence for birds approaching the observer; for these cases we selected the following interval bands: 0, 60, 120 and 180 m.

# ***South African Bird Atlas Project reporting rates***

The second Southern African Bird Atlas Project (SABAP2) was initiated in July 2007 and is ongoing. The SABAP2 spatial sampling unit is the “pentad” which covers 5 minutes of latitude by 5 minutes of longitude (5’×5’). The number of times a species occurs in a set of lists divided by the total number of lists submitted by bird watchers for a pentad is the reporting rate. For instance, if a pentad has 10 submitted lists, and one species occurs on only one list, then the reporting rate for that species is 10%. We downloaded all reporting rate data for the species observed during survey 1 from sabap2.adu.org.za on 19 January 2015. We then calculated mean reporting rates for each species for those pentads covered in survey 1. As the reporting rate for each pentad is a summary for the duration of SABAP2, we cannot account for the influence of climate or habitat change at this scale.

# **Statistical analysis**

# ***Which detection covariates best explain relative abundance?***

To examine detection covariates influencing survey 1 relative abundance for this community of bird species (N = number of species), we use the dredge function in the R package MuMIN ([Barton 2011](#_ENREF_4)) to create a table of competing models from the following starting model: survey 1 relative abundance ~ mean bird density + group size + vegetation height + mobility +tolerance score + mass + rank colour + modified preference score + vocalization score. We examine an average model based on those models within AICc <2 of the top model. We used this model, as well as the top model by AIC and the most parsimonious model with only significant covariates, and a model containing only density, to predict relative abundance from survey 2 in a cross validation exercise. For this exercise we updated density estimates, group size, tolerance, vegetation height, mobility and vocalization coefficients with those calculated for survey 2, but held mass, colour and modified habitat preference coefficients constant as used in survey 1. We tested the relationship between predicted relative abundance and actual relative abundance from survey 2 using Spearman’s ranked correlation analysis.

# ***Bird densities and SABAP2 reporting rates***

To explore the relationship between density values obtained from survey 1 and SABAP2 reporting rates we tested for correlations between density with: a. mean reporting rate for the set of all species; b. reporting rate for the subset of species excluding those that showed a preference for modified habitats; and c. reporting rates divided by detection covariates (an alternative approach to exploring interaction effects). From this process we identified a relationship between density and reporting rates divided by mass. Using this relationship we created a predictive linear model for density (density ~ mean reporting rate / mass). We tested linear model assumptions using the gvlma package in R ([Pena and Slate 2010](#_ENREF_26)). To validate the model predictions, we calculated 95% confidence interval for densities of the Fynbos endemic bird species from the reporting rate / mass relationship using all available SABAP2 data. Population estimates were then calculated for these species as: number of pentads in which a species was recorded \* pentad area (81 km2) \* density confidence intervals. To test whether this model is applicable to a wider range of species outside the Fynbos we further predicted population size using this model and SABAP2 data for the set of southern African endemic species for which population estimates were available from the Birdlife International’s Datazone ([BirdLife International 2015](#_ENREF_5)).

# **Results**

# ***Which detection covariates best explain relative abundance?***

Bird density estimates and the tolerance score were the significant predictors explaining relative abundance of Fynbos birds in the averaged model, composed of five models within 2 AICc points of the top-performing model (the complete model summary table is supplementary information 2). All other potential detection covariates were non-significant components. The top model by AIC contained the covariates: density, group size, vocalization, mobility and vegetation height as significant predictors. However, vegetation height proved to be a confounding non-linear variable; birds at either end of the variable’s range showed low abundance. For a model using vegetation height as an offset (a term to be added to a linear predictor with known coefficient 1 rather than an estimated coefficient), density was the only significant predictor variable in the resulting model. The relationships between relative abundance and the individual variables in this model are illustrated in Fig. 1.

For our validation exercise, the correlation between the survey 2 relative abundance and predicted values was strongest for the simplest model with only bird density (rs = 0.64, p = 0.001, df = 30; Table 1). Correlations with the top model and top model with vegetation offset were intermediate, while there was no correlation with predicted values from the averaged model.

# ***Bird densities and SABAP2 reporting rates***

The survey 1 point counts were conducted in 124 pentads. Correlation between densities and SABAP2 reporting rate from these pentads was not significant (rs = 0.25, p = 0.16, df = 30, Fig. 2). Reporting rates for several species associated with modified landscapes were higher than expected by mean densities calculated from the Fynbos.

Dividing reporting rates by mass did result in a significant positive correlation with density estimates calculated using Distance (rs = 0.72, p < 0.001, df = 30; Fig. 3). Predicted densities and populations from SABAP2 data based on the model of this relationship are presented in Table 2 for Fynbos endemic species as well as species outside the biome. Correcting reporting rates by dividing by the modified habitat preference score, or by the tolerance score, did not improve correlations significantly (modified score: rs = 0.23, p = 0.21; tolerance: rs = -0.32, p = 0.07, df = 30).

Fynbos bird density estimates from SABAP2 reporting rates were generally lower compared to our previously published estimates (Table 2). The Cape Rockjumper SABAP2 density estimate was higher, but this was calculated from a much smaller area than the other species and when standardizing reporting area results to the bioregion area surveyed by [Lee and Barnard (2015)](#_ENREF_23) results were comparable (0.44 – 0.54 individuals / km2 95% CI for corrected SABAP2 derived density estimates). Upper population estimates for all SABAP2 derived metrics were lower than those presented by [Lee and Barnard (2015)](#_ENREF_23), with upper estimates most comparable for Orange-breasted Sunbird (SABAP2 UCI estimate 69% the value of the Lee and Barnard 2015 estimate), but dramatically lower for Protea Seedeater at 8% even though density estimates overlapped.

Almost all upper population estimates for the validation set of birds with ranges outside the Fynbos were at least twice as high compared to published population estimates (from Lee and Barnard 2015). Population estimates from SABAP2 data were particularly poor for large bird species, with those for the Southern Bald Ibis and nomadic Black Harrier unrealistic given knowledge of these species. The near concordance of estimates from Ludwig’s Bustard are likely a function of incomplete atlas coverage across that species Karoo habitat. There was some evidence for overlap in population projections for grassland passerines. However, this method for population extrapolation to forest species may produce higher than expected population estimates due to the small fragmented nature of this habitat within a pentad, in addition to differences resulting from detection function and reporting rate patterns.

# **Discussion**

# ***Covariates of detection***

Modelling of a point-count based relative-abundance index identified several variables that influence detection, the most important being bird tolerance towards the observer. Bird density was a significant predictor of relative abundance in all output models. It has been shown for Australian atlas data that reporting rates are monotonically related to abundance, although not linearly ([Griffioen 2001](#_ENREF_16)). Bird density has also been reported to correlate with an index of relative abundance derived from mist-netting capture rates in the Fynbos ([Lee, et al. 2015](#_ENREF_22)).

Intuitively, species that are tolerant of, or even attracted to, human observers will be recorded more frequently compared to species that display avoidance behaviour and so which might escape an observer undetected. Indeed, approach behaviour by birds to observers is often a confounder of density estimation modelling ([e.g. Sillett, et al. 2012](#_ENREF_33)). Orange-breasted Sunbird density estimation was complicated in this study due to birds approaching the observer. This tolerance score, no doubt influenced by a species predilection for being a ‘sentinel’ species, will be important for regions where mixed-flocks occur, which are often characterized the presence of species known for alerting others to the presence of potential predators ([Goodale and Kotagama 2008](#_ENREF_15)). Habituation to human presence will also impact detectability since non-habituated birds will flush at larger distances ([Blumstein 2013](#_ENREF_7), [Samia and Blumstein 2015](#_ENREF_31)) with generally lower chances of detection. In this case detection will also be a function of flight behaviour: if alarm calls or wing-beats are given on flight these birds may in fact be more detectable. While the use of this score did not improve the relationship between SABAP2 reporting rates and density estimates here, it may be a useful metric elsewhere or at the individual species level.

Vocalization and mobility were also tentatively identified as being positively correlated with relative abundance. In surveys of land birds, an observer usually hears more birds than are seen, and counts based largely on aural cues are routinely used to index bird abundance. Using suitable equipment, vocal cues can even be used to calculate density ([Dawson and Efford 2009](#_ENREF_10)). Flying birds are far more likely to be detected than birds that remain stationary and are potentially concealed. In addition, social birds will often call either in alarm or for group cohesion ([Farnsworth 2005](#_ENREF_13)).

The issue of detection of birds during surveys has been recognised as an issue for a long time, with various techniques used to tackle the issue ([Buckland, et al. 2005a](#_ENREF_8), [Nichols, et al. 2000](#_ENREF_25)). Recent publications exploring ecological processes from SABAP data have used occupancy modelling techniques that attempt to account for the observation process ([Bled, et al. 2013](#_ENREF_6)). However, while probability of occupancy of any given area is improved when accounting for the observation process, the scale of these studies has been coarse and the technique is suitable for only a small set of species. As of yet, no density or population estimates have resulted from occupancy modelling using the SABAP2 dataset.

# ***Density and atlas reporting rates***

For the first time for SABAP2 data we attempt to explicitly explore several species’ behavioural and biological attributes that would account for variation in detection and thus reporting rates. While we expected bird density to be the best explanatory variable from the relationship between density and relative abundance modelled above, the relationship with atlas reporting rates was confounded by birds tolerant of human-modified habitats. These had higher reporting rates than expected. To a degree this is not a surprise: most citizen scientist observation efforts will at the very least start in human modified habitats, if not cover them explicitly. The influence of roads on bird distribution is well reported, for instance it has been demonstrated that Orange-breasted Sunbird avoid the road verge ([Geerts and Pauw 2011](#_ENREF_14)).

For this set of Fynbos birds for which densities could be calculated, most were small passerines, and we identified a relationship with reporting rates when correcting when accounting for mass. Given all else is equal, larger birds are more easily detected, but otherwise this relationship was unexpected given the modelling exercise on correlations of relative abundance from the single observer data set. However, the relative abundance index was created from point counts conducted on foot, while most SABAP2 lists are likely compiled to a degree while driving, when larger birds will be more readily detected and hence the importance of mass over the detection covariates.

Our density estimates for Fynbos endemic bird species calculated from SABAP2 reporting rates broadly agreed with those published in [Lee and Barnard (2015)](#_ENREF_23). While population estimates were consistently lower, the existing published values were based on extrapolation of density estimates to the possible extent of occurrence of these species. This was an area in some cases much larger than the area represented by our current conversion of pentads to area from which population estimates from SABAP2 data were calculated. The pentad area better represents a species area of occupancy for species whose range has been well covered by atlasing efforts. Area of occupancy is typically an area contained within a species extent of occurrence. While this suggests lower SABAP2 population estimates are valid for the Fynbos endemic bird species as they are conservative, upper confidence interval values are possibly underestimated. In the case of the drab-coloured Protea Seedeater, a species with very low detection probability ([Lee, et al. 2015](#_ENREF_22)), the upper confidence interval reported by SABAP2 would need to be multiplied by ten to be comparable to published values. This is an important consideration given that atlas efforts are patchy and species are unlikely to be reported from all areas in which they do occur, which is likely to be the case for species inhabiting inaccessible mountain regions.

The technique presented here to estimate densities and populations was trained on a dataset of mostly small, passerine species from the Fynbos. Given the unique set of conditions that lead to reporting rates for different biomes, it is not surprising that population estimates derived from atlas data for species outside the Fynbos are in doubt. Estimations for large species were particularly poor, suggesting that better correction factors are needed for large birds. Migratory and nomadic species may well be unsuitable candidates for population extrapolation from reporting rates unless using single season locations. This is because migratory and nomadic species may be recorded over large areas while in passage even though they do not actually use these areas e.g. Black Harrier from this study. Should more population estimates for other South African birds become available it should be possible to create a model for other species in other biomes. Likewise, training existing reporting rate data for other atlas efforts on known populations or densities will provide a method to then estimate these metrics for other populations or atlas projects.

# **Acknowledgements**

The impressive SABAP and SABAP2 datasets would not exist without huge effort by the citizen science atlas community, coordinated and managed by Les Underhill and Michael Brooks. Support for this study was received from BirdLife South Africa, Percy FitzPatrick Institute of African Ornithology DST–NRF Centre of Excellence, the Lee Family Trust and Rockjumper Birding Tours. This research was conducted under CapeNature permit 0056-AAA041-00001 and Eastern Cape Parks and Tourism Agency permit RA 0116. We thank Will Cresswell for comments that helped greatly improve this manuscript.

# **Conflict of Interest**

Alan Lee is the current Editor-in-chief at Ostrich at the time of acceptance of this article. However, submission and review of the article were performed prior to this appointment, with the revised article accepted by Associate Editor Genevieve Jones, with production editor Lizanne Roxburgh.

# **References**

Amar A, Cloete D, Whittington M. 2015. Using independent nest survey data to validate changes in reporting rates of Martial Eagles between the Southern African Bird Atlas Project 1 and 2. *Ostrich*, 87: 1-5.

Barnard P, Villiers Md (eds). 2012. *Biodiversity early warning systems: South African citizen scientists monitoring change*. Pretoria, South Africa: South African National Biodiversity Institute.

Barnes KN. 2000. *The Eskom red data book of birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa.

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.

BirdLife International. 2015. IUCN Red List for birds. Downloaded from <http://www.birdlife.org> on 23/04/2015.].

Bled F, Nichols JD, Altwegg R. 2013. Dynamic occupancy models for analyzing species' range dynamics across large geographic scales. *Ecology and Evolution*, 3: 4896-4909.

Blumstein DT. 2013. Attention, habituation, and antipredator behaviour: implications for urban birds. *Avian Urban Ecology: Behavioural and Physiological Adaptations*: 41.

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

Buckland ST, Anderson DR, Burnham KP, Laake JL. 2005b. *Distance sampling*. Wiley Online Library.

Dawson DK, Efford MG. 2009. Bird population density estimated from acoustic signals. *Journal of Applied Ecology*, 46: 1201-1209.

Dickinson JL, Zuckerberg B, Bonter DN. 2010. Citizen science as an ecological research tool: challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics*, 41: 149-172.

Downs CT. 2005. Abundance of the endangered Cape parrot, Poicephalus robustus, in South Africa: implications for its survival. *African Zoology*, 40: 15-24.

Farnsworth A. 2005. Flight calls and their value for future ornithological studies and conservation research. *The Auk*, 122: 733-746.

Geerts S, Pauw A. 2011. Easy technique for assessing pollination rates in the genus Erica reveals road impact on bird pollination in the Cape fynbos, South Africa. *Austral Ecology*, 36: 656-662.

Goodale E, Kotagama SW. 2008. Response to conspecific and heterospecific alarm calls in mixed-species bird flocks of a Sri Lankan rainforest. *Behavioral Ecology*, 19: 887-894.

Griffioen P. 2001. Temporal changes in the distributions of bird species in eastern Australia. PhD dissertation, La Trobe University.

Harrison J, Underhill L, Barnard P. 2008. The seminal legacy of the Southern African bird atlas project. *South African Journal of Science*, 104: 82-84.

Hockey P, Dean WRJ, Ryan P (eds). 2005. *Roberts birds of southern Africa* (7 edn). Johannesburg: Trustees of the John Voelcker Bird Book Fund.

IUCN Standards and Petitions Subcommittee. 2014. *Guidelines for Using the IUCN Red List Categories and Criteria. Version 11. Prepared by the Standards and Petitions Subcommittee. Downloadable from* [*http://www.iucnredlist.org/documents/RedListGuidelines.pdf*](http://www.iucnredlist.org/documents/RedListGuidelines.pdf)*.*

Kéry M. 2011. Towards the modelling of true species distributions. *Journal of Biogeography*, 38: 617-618.

Lebreton J, Clobert J. 1991. Bird population dynamics, management, and conservation: the role of mathematical modelling. *Bird population studies*: 105-125.

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, Barnard P. 2015. Endemic birds of the Fynbos biome: a conservation assessment and impacts of climate change. *Bird Conservation International*, 26: 52-68.

Milne R. 2014. Physiological tolerances of high temperatures in Fynbos birds: implications for climate change. MSc, University of Cape Town.

Nichols JD, Hines JE, Sauer JR, Fallon FW, Fallon JE, Heglund PJ. 2000. A double-observer approach for estimating detection probability and abundance from point counts. *The Auk*, 117: 393-408.

Pena EA, Slate EH 2010. gvlma: Global Validation of Linear Models Assumptions. R package version.

Péron G, Altwegg R. 2015. Low bird diversity in the Fynbos plant diversity hotspot: Quaternary legacies in the current distributions of passerine birds. *Ecography*: doi: 10.1111/ecog.01176.

Pollock KH, Marsh H, Bailey LL, Farnsworth GL, Simons TR, Alldredge MW. 2004. Separating components of detection probability in abundance estimation: an overview with diverse examples. In: Thompson WL editor. *Sampling rare or elusive species*. London: Island Press. p. 43-58.

Robertson A, Simmons RE, Jarvis AM, Brown CJ. 1995. Can bird atlas data be used to estimate population size? A case study using Namibian endemics. *Biological Conservation*, 71: 87-95.

Rosenstock SS, Anderson DR, Giesen KM, Leukering T, Carter MF, Thompson III F. 2002. Landbird counting techniques: current practices and an alternative. *The Auk*, 119: 46-53.

Samia DS, Blumstein DT. 2015. Birds flush early and avoid the rush: an interspecific study. *PLoS ONE*, 10: e0119906.

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.

Sillett TS, Chandler RB, Royle JA, Kéry M, Morrison SA. 2012. Hierarchical distance-sampling models to estimate population size and habitat-specific abundance of an island endemic. *Ecological Applications*, 22: 1997-2006.

Taylor MR, Peacock DS, Wanless RM. 2015. *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. Johannesburg: BirdLife South Africa.

Thomas L, Buckland ST, Rexstad EA, Laake JL, Strindberg S, Hedley SL, Bishop JR, Marques TA, Burnham KP. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, 47: 5-14.

Williams BK, Nichols JD, Conroy MJ. 2002. *Analysis and management of animal populations*. Academic Press.

Table 1: Model coefficients summary table for five models explaining relative abundance of a point count survey as a function of detection covariates. N = 32 species. Variables not significant in any models were mass and rank colour. Parsimonious model includes only the significant predictors from the averaged model. The test statistic for the averaged model is a z score, while that for all other models is a t value. P values lower than 0.05 are highlighted in bold.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Model: | Coefficients | Estimate | Std. Error | t/z value | Pr(>|t/z|) |
| Average | Intercept | 173.92 | 114.03 | 1.48 | 0.140 |
|  | Density | 5.43 | 2.32 | 2.23 | **0.026** |
|  | Tolerance | 1010.05 | 403.67 | 2.40 | **0.016** |
|  | Group size | -19.22 | 29.20 | 0.65 | 0.516 |
|  | Vocalization | 193.86 | 160.17 | 1.19 | 0.235 |
|  | mobility | -247.95 | 198.34 | 1.22 | 0.221 |
|  | modified | -270.51 | 484.26 | 0.55 | 0.581 |
|  | Vegetation | -80.26 | 50.58 | 1.55 | 0.121 |
| Top | Intercept | 157.84 | 103.40 | 1.53 | 0.139 |
|  | Density | 5.35 | 2.26 | 2.37 | **0.026** |
|  | Tolerance | 1135.60 | 380.77 | 2.98 | **0.006** |
|  | Vocalization | 243.17 | 111.60 | 2.18 | **0.039** |
|  | Mobility | -355.64 | 139.72 | -2.55 | **0.018** |
|  | Vegetation | -105.00 | 37.22 | -2.82 | **0.009** |
| Top, no Veg | Intercept | 57.36 | 109.68 | 0.52 | 0.605 |
|  | Density | 5.86 | 2.54 | 2.31 | **0.029** |
|  | Tolerance | 647.51 | 383.71 | 1.69 | 0.104 |
|  | Vocalization | 125.71 | 117.02 | 1.07 | 0.293 |
|  | Mobility | -230.14 | 149.63 | -1.54 | 0.136 |
| Parsimonious | Intercept | 87.96 | 46.51 | 1.89 | 0.069 |
|  | Density | 7.57 | 2.50 | 3.03 | **0.005** |
|  | Tolerance | 226.25 | 322.34 | 0.70 | 0.489 |
| Density only | Intercept | 106.27 | 38.17 | 2.78 | **0.009** |
|  | Density | 8.17 | 2.33 | 3.51 | **0.002** |

Table 2: A comparison between density (individuals / km2), population estimates resulting from SABAP2 reporting rate data and published values for Fynbos birds, as well as for birds outside the Fynbos. Mass is presented in grams. Pentads are the number of SABAP2 recording units that contain records for that species. Sd = reporting rate standard deviation; LCI = lower 95% confidence interval; UCI = upper 95% confidence interval. Published density and population estimates for Fynbos birds are from [Lee and Barnard (2015)](#_ENREF_23). Non-Fynbos population estimates were obtained from Birdlife Datazone species accounts, which cites [Barnes (2000)](#_ENREF_3), with the exception of Cape Parrot ([from Downs 2005](#_ENREF_12)) and Ludwig’s Bustard ([Shaw, et al. 2015](#_ENREF_32)). Biome indicates biome preference of range restricted species. Status is the Birdlife South Africa conservation status ([Taylor, et al. 2015](#_ENREF_34)).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  | Density |  |  |  | Population Estimates (x1000) | | |  |
| Name |  |  | SABAP2 reporting rate | | | | SABAP2 density | | Published estimates | | SABAP2 population | | Published estimates |  |
| Fynbos birds | Mass | pentads | Mean | sd | LCI | UCI | LCI | UCI | LCI | UCI | LCI | UCI | LCI | UCI |
| Cape Rockjumper | 52.9 | 76 | 26.4 | 26.5 | 20.4 | 32.3 | 4.2 | 5.1 | 0.6 | 1.0 | 25 | 32 | 32 | 59 |
| Victorin's Warbler | 17.0 | 182 | 33.6 | 28.7 | 29.5 | 37.8 | 9.9 | 12.0 | 12.0 | 15.3 | 145 | 177 | 697 | 889 |
| Cape Sugarbird | 33.8 | 578 | 45.1 | 31.2 | 42.6 | 47.7 | 7.9 | 8.5 | 23.6 | 30.3 | 369 | 400 | 1371 | 1761 |
| Orange-breasted Sunbird | 9.2 | 454 | 39.4 | 31.1 | 36.6 | 42.3 | 19.4 | 22.0 | 16.7 | 20.1 | 713 | 811 | 970 | 1168 |
| Cape Siskin | 13.1 | 361 | 29.4 | 25.1 | 26.8 | 32.0 | 11.2 | 12.9 | 10.5 | 21.9 | 328 | 378 | 610 | 1272 |
| Protea Seedeater | 20.9 | 117 | 19.8 | 23.3 | 15.6 | 24.0 | 5.7 | 7.4 | 6.8 | 14.3 | 54 | 71 | 395 | 831 |
| Non-Fynbos birds | Mass | pentads | Mean | sd | LCI | UCI | Biome | Status |  |  | SABAP2 population |  | Published estimates |  |
| Botha’s Lark  *Spizocorys fringillaris* | 19 | 14 | 29.1 | 24.7 | 16.2 | 42.1 | Grassland | EN |  |  | 6 | 14 | 1.5 | 5 |
| Knysna Warbler  *Bradypterus sylvaticus* | 21 | 86 | 12.3 | 11.6 | 9.9 | 14.8 | Forest | VU |  |  | 31 | 39 | 3.5 | 15 |
| Yellow-breasted Pipit  *Anthus chloris* | 25 | 65 | 26.5 | 24.8 | 20.5 | 32.5 | Grassland | VU |  |  | 31 | 43 | 2.5 | 6.5 |
| Rudd’s Lark  *Heteromirafra ruddi* | 26 | 13 | 31.0 | 22.9 | 18.6 | 43.5 | Grassland | EN |  |  | 5 | 11 | 1.5 | 5 |
| Bush Blackcap  *Lioptilus nigricapillus* | 31 | 134 | 22.7 | 24.2 | 18.6 | 26.8 | Grassland/Forest | VU |  |  | 55 | 68 | 1.5 | 5 |
| Red Lark  *Calendulauda burra* | 37 | 57 | 77.6 | 29.8 | 69.8 | 85.3 | Karoo | VU |  |  | 48 | 57 | 6.3 | 9.4 |
| Knysna Woodpecker  *Campethera notate* | 62 | 343 | 33.1 | 27.2 | 30.2 | 36.0 | Forest | NT |  |  | 128 | 139 | 1.5 | 5 |
| Cape Parrot  *Poicephalus robustus* | 300 | 67 | 35.4 | 26.8 | 29.0 | 41.8 | Forest | EN |  |  | 15 | 17 | 0.5 | 1 |
| Black Harrier  *Circus maurus* | 550 | 733 | 26.0 | 26.5 | 24.0 | 27.9 | Generalist | EN |  |  | 161 | 164 | 1 | 1.5 |
| Southern Bald Ibis  *Geronticus calvus* | 1100 | 953 | 46.2 | 31.6 | 44.2 | 48.2 | Grassland | VU |  |  | 209 | 211 | 8 | 10 |
| Blue Korhaan  *Eupodotis caerulescens* | 1300 | 962 | 55.4 | 33.1 | 53.3 | 57.5 | Grassland | LC |  |  | 211 | 213 | 12 | 15 |
| Ludwig's Bustard  *Neotis ludwigii* | 7000 | 949 | 58.2 | 35.8 | 55.9 | 60.4 | Karoo | EN |  |  | 198 | 199 | 87 | 148 |

Figure captions

Figure 1: Detection variable relationships with relative abundance from a point-count survey across the Fynbos biome (survey 1). Best fit lines and standard error bands are displayed for each chart.

Figure 2: Correlation between bird densities and mean SABAP2 reporting rate for bird species from pentads in which the survey 1 was conducted. Point size is weighted by modified habitat preference scores. Those species with modified habitat scores >10% are labelled.

Figure 3: The relationship between mean SABAP2 reporting rate divided by species mass and bird densities calculated here for the Fynbos region using the program Distance 6.2. The regression line of the relationship is drawn together with standard error bands as shading.