



HAL
open science

Land use effects on phylogenetic and functional diversity of birds: Significance of urban green spaces

Justice Muvengwi, Hervé Fritz, Monicah Mbiba, Hilton G T Ndagurwa

► To cite this version:

Justice Muvengwi, Hervé Fritz, Monicah Mbiba, Hilton G T Ndagurwa. Land use effects on phylogenetic and functional diversity of birds: Significance of urban green spaces. *Landscape and Urban Planning*, 2022, 225, pp.104462. 10.1016/j.landurbplan.2022.104462 . hal-03851446

HAL Id: hal-03851446

<https://hal.science/hal-03851446v1>

Submitted on 31 Oct 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL
open science

Land use effects on phylogenetic and functional diversity of birds: Significance of urban green spaces

Justice Muvengwi, Herve Fritz, Monicah Mbiba, Hilton G T Ndagurwa

► To cite this version:

Justice Muvengwi, Herve Fritz, Monicah Mbiba, Hilton G T Ndagurwa. Land use effects on phylogenetic and functional diversity of birds: Significance of urban green spaces. *Landscape and Urban Planning*, 2022, 225, pp.104462. 10.1016/j.landurbplan.2022.104462 . hal-03851446

HAL Id: hal-03851446

<https://hal.science/hal-03851446>

Submitted on 31 Oct 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Land use effects on phylogenetic and functional diversity of birds: Significance of urban green spaces

Justice Muvengwi^{a,b,e,*}, Herve Fritz^{a,b,c}, Monicah Mbiba^a, Hilton G.T. Ndagurwa^{d,e}

^a Sustainability Research Unit, Nelson Mandela University, George Campus, P/Bag X6531, George 6530, South Africa

^b REHABS, CNRS-UCBL-NMU International Research Laboratory, Nelson Mandela University, George Campus, P/Bag X6531, George 6530, South Africa

^c LTSER France, Zone Atelier "Hwange," Hwange National Park, Bag 62, Dete, Zimbabwe – CNRS HERD (Hwange Environmental Research Development) Program, Dete, Zimbabwe

^d Department of Forest Resources & Wildlife Management, Faculty of Applied Science, National University of Science & Technology, P.O. Box AC 939, Ascot, Bulawayo, Zimbabwe ^e School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, Johannesburg 2050, South Africa

HIGHLIGHTS

- Species richness per sampling point was high in Harare compared with Chivero Park.
- Bird functional diversity was higher in Harare than Chivero Park.
- Phylogenetic diversity was higher in Chivero Park than Harare.
- Proportional species richness for the different functional groups was similar between sites.

ARTICLE INFO

Keywords:

Birds
Functional diversity
Phylogenetic diversity
Protected areas
Species richness
Zimbabwe

ABSTRACT

Although research has been done in order to understand the impact of urban development on avian diversity, it mainly focused on taxonomic diversity. Here we aimed to assess biodiversity targeting beyond species richness since this has the potential to inform the conservation of healthy functioning ecosystem. We explored how functional and phylogenetic diversity vary between a protected area and urban green spaces. We collected avian data at Lake Chivero Park and six green spaces in the city of Harare, Zimbabwe. The avian point count method at 30 sites for each location (Harare and Lake Chivero Park) was conducted. Alpha diversity indices were compared between Harare and Lake Chivero Park using independent *t*-test. One-way analysis of variance was applied to test for variation in functional and phylogenetic beta-diversity metrics together with the respective standardized effect size. Urban green spaces had higher species richness, abundance, phylogenetic and functional diversity than Lake Chivero Park. Beta diversity between the two sites was much higher than within sites diversity. The two sites did not differ in terms of beta diversity. Our study shows that urban development that incorporates green spaces maybe critical in the conservation of functional and phylogenetic diversity of avifauna. We suggest that urban landscapes be considered in national and regional conservation plans since they can act as conduits between protected areas, especially for avifauna.

1. Introduction

Urbanization has profound effects on biodiversity. It has been singled out as one major contributor to biotic homogenization (McKinney, 2006). However with proper planning during development urban landscapes can conserve biodiversity. The urban landscape matrix house a great deal of species both native and nonnative (Aronson et al., 2014; Ives et al., 2016;

Lepczyk et al., 2017; Lepczyk, Aronson et al., 2017). Urban green spaces comprise a range of habitat types that cross a continuum from intact remnant patches of native vegetation, brownfields, gardens, and yards, to essentially terraformed patches of vegetation that may or may not be representative of native community associations (Lepczyk, Aronson et al., 2017). All these urban green spaces play several ecosystem functions.

* Corresponding author at: Sustainability Research Unit, Nelson Mandela University, George Campus, P/Bag X6531, George 6530, South Africa. E-mail address:

justicemuvengwi@gmail.com (J. Muvengwi). <https://doi.org/10.1016/j.landurbplan.2022.104462>

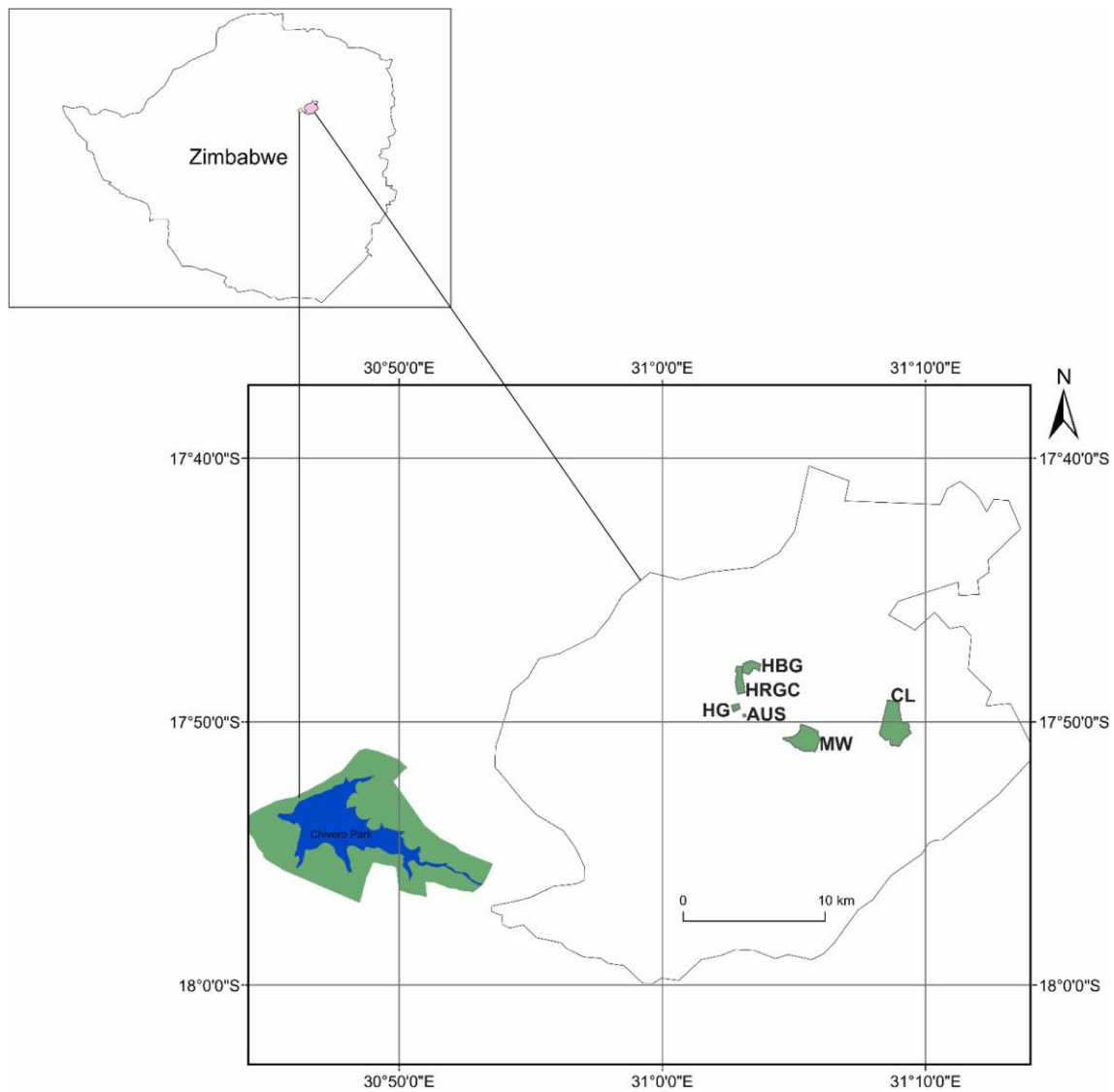


Fig. 1. Map showing location of the study sites, Harare and Lake Chivero Park. Harare gardens (HG), Harare Golf Course (HRGC), Africa Unit Square (AUS), Mukuvisi Woodlands (MW), Harare botanical gardens (HBG) and Cleveland Park (CL).

Green spaces reduce surface runoff because most of the rainwater infiltrates, however, the development of tared roads and pavements reduces permeable surfaces in urban communities which increase surface runoff and urban flooding (Armson, Stringer, & Ennos, 2013). Urban vegetation sequesters carbon thereby reduce the amount of carbon from industries and automobiles (Vailshery, Jaganmohan, & Nagendra, 2013; Yang, McBride, Zhou, & Sun, 2004). Urban green spaces also provide cultural services such as, aesthetics, recreation and heritage which are important for human well-being (Threlfall & Kendal, 2016). Urban green spaces are critical habitats to support biodiversity, but we still have a limited understanding of their ecology and how they function to conserve biodiversity at local and landscape scales across multiple taxa (Lepczyk, Aronson et al., 2017; Lepczyk, Sorte, et al., 2017). Many cities in Africa lack studies on how urban green spaces contribute to biodiversity conservation (Aronson et al., 2014; Ibañez- ~ Alamo, Rubio, Benedetti, & Morelli, 2017; La Sorte et al., 2018; McKinney, 2006).

One way of understanding the extent to which urban green spaces contribute to biodiversity is to compare them to regional areas (e.g. East Africa, West Africa, North Africa or Southern Africa) where they are located. In a study focusing on birds, compared to regional assemblages, urban assemblages contained lower phylogenetic diversity and lower phylogenetic beta-diversity (La Sorte et al., 2018). Similarly, urban-rural gradient research

has shown that increased urbanization leads to decreased species richness (Lepczyk et al., 2008) but an increase in total avian biomass due to the dominance of a few urban dwelling species (Clergeau, Croci, Jokimaki, " Kaisanlahti-Jokimaki, " & Dinetti, 2006; Garaffa, Filloy, & Bellocq, 2009). Within cities, bird species density was highest in cities with the lowest proportion of urban land cover (Aronson et al., 2014), indicating that the provision of green space at the city scale is crucial to bird species conservation in cities (Chace & Walsh, 2006; Evans, Newson, & Gaston, 2009). For example, there is evidence that remnant patches of intact vegetation within urban areas retain macroecological patterns similar to those found in patches of intact vegetation outside urban areas (Pautasso et al., 2011). In developing countries, there is rapid expansion of urban development, therefore understanding the drivers of biodiversity in urban green spaces is valuable to global biodiversity conservation (Aronson et al., 2017). Indeed, biodiversity studies that target beyond species richness have the potential to inform the preservation of health, functioning ecosystem (Cadotte, Carscadden, & Mirotchnick, 2011). In order to achieve this we considered indices that targeted functional (Bregman et al., 2016; Chapman, Tobias, Edwards, & Davies, 2018) and phylogenetic diversity (Chapman et al., 2018; Jarzyna & Jetz, 2016; Lopez et al., 2016).

Functional diversity (FD) is the sum of branch lengths in a dendrogram generated from functional trait differences (Petchey & Gaston, 2002, 2006),

and can be better proxy for explaining ecosystem functioning than classical measures of taxonomic diversity (e.g. species richness, Simpson's diversity index) (Cadotte et al., 2011). High dissimilarity between species result in higher FD, which, therefore, provides an index of niche complementarity and the diversity of ecological interactions present within communities (Cadotte et al., 2011; Cadotte, Dinnage, & Tilman, 2012; Chapman et al., 2018). The alternative metric of FD, phylogenetic diversity (PD), measures the evolutionary relatedness among species in a community. PD is defined as the total phylogenetic distance among two or more species (Faith, 1992), explicitly measuring species differences rather than species numbers or traits. Phylogenetic diversity is inversely proportional to the evolutionary relatedness of the species, and higher PD is obtained when species are more distantly related (Venail et al., 2015). Greater PD and FD have been found to be correlated with higher ecosystem functioning, stability and productivity compared with species richness (Cadotte et al., 2011, 2012). Our understanding of how biodiversity metrics such as PD and FD differ between urban areas and protected areas remains limited (but see. La Sorte et al., 2018; Weideman, Slingsby, Thomson, & Coetzee, 2019). Indeed, the effect of urbanization on phylogenetic diversity remains unclear (Morelli et al., 2016).

We considered birds because they have been shown to be good indicator species in studies considering the effect of urbanization on ecosystems (Ibañez-Alamo et al., 2017; Suri, Anderson, Charles-dominique, Hellard, & Cumming, 2017). Furthermore, the ecology of birds is well understood (Edwards et al., 2014; Fontana, Sattler, Bontadina, & Moretti, 2011), the link between foraging guilds and ecological functioning is relatively well established (Suri et al., 2017; Wenny et al., 2011), their phylogeny has been well established (Hackett et al., 2008; Jetz, Thomas, Joy, Hartmann, & Mooers, 2012) and they respond quickly to changes in habitat and plant community structure (Chapman et al., 2018; Hughes, Edwards, Sayer, Martin, & Thomas, 2020).

Our research gap is whether urban green spaces can support functional and phylogenetic diversity of birds comparable to regional protected areas. In order to achieve this aim we developed the following objectives: (i) to determine bird species abundance, richness and diversity between a protected area and urban green spaces (ii) to determine functional and phylogenetic alpha and beta diversity of birds in green spaces in Harare and Chivero Park. We expected urban green spaces to maintain functional and phylogenetic diversity that is lower to that of Chivero Park since fewer species (urban exploiters) have been observed to benefit from cities (Ibañez-Alamo et al., 2017; La Sorte et al., 2018).

2. Materials and methods

2.1. Description of study sites

The study was carried out in Harare (18°00' S, 31°15' E) the capital city of Zimbabwe and Chivero Park (17° 90' S, 30° 79' E) south west of Harare (Fig. 1). Rainfall varies between 650 and 850 mm and 700–830 mm for Harare and Chivero Park, respectively. The rainy season span between November and March. Harare and Chivero Park experience hot wet season from November to April, a cool dry season from May to July and a hot dry season from August to October (Mbiba, Mazhude, Fabricius, Fritz, & Muvengwi, 2021; Muvengwi, Kwenda, Mbiba, & Mpindu, 2019). The area between Harare and Chivero Park comprise of commercial farms. The vegetation of Chivero Park is of miombo, characterized by *Brachystegia* and *Julbernardia* sp. (Caesalpinioideae). In Harare, we sampled six green spaces, two urban gardens, Harare gardens (HG: 20 ha of mixed exotic and indigenous trees), Africa Unity Square (AUS: 3 ha of exotic trees), Harare Golf Course (HRGC: 86 ha of mainly indigenous trees of the miombo type), Cleveland Park (CL: 273 ha of miombo woodland and a small dam), Mukuvisi Woodlands (MW: 262 ha

Table 1

Bird foraging guilds that were used to put all the birds that were recorded in this study (Sekercioglu, 2006; Suri et al., 2017).

Foraging Group	Definition
Insectivores	Insect-eating birds
Grazers	Feeding on grass
Frugivores	Birds that feed on fruits and the seeds from the fruits pass through their digestive tracts deposited in other areas
Granivores	Seed-eating birds
Raptors	Birds of prey
Nectarivores	Birds that pollinate plants when feeding on nectar
Scavengers	Feeding on carrion material or waste

of miombo woodland and a perennial river) and Harare botanical gardens (HBG: 74 ha of miombo woodland) (Fig. 1, Appendix A).

2.2. Data collection/Sampling protocol

Field surveys were conducted between December 2018 and February 2019, a time when migrant species are around, and most species are breeding. A total of 60 sampling points were surveyed between Harare and Chivero Park, thirty points at each site. Sampling points were randomly marked considering a minimum distance of at least 300 m spacing between them to avoid pseudo-replication ensuring statistical independence (van Rensburg, Peacock, & Robertson, 2009). Surveys were conducted early morning during the first 3.5 h after sunrise, a period of high bird activity (Suri et al., 2017). Recording at each point involved a five minutes habituation time (a decrease in response of birds to human presence) which was followed by a 15 min counting time of all the birds in a radius of 150 m (Suri et al., 2017). Our point counts were conducted by one observer. Sampling points were visited in a random order between Harare and Chivero Park. All the bird species that were seen or heard within the radius were recorded. We classified bird species as threatened with extinction if they were categorized as critically endangered (CR), endangered (EN) or vulnerable (VU) under the IUCN Red List in their native range, otherwise they were considered under least concern (LC) (IUCN, 2011).

2.3. Phylogenetic tree construction and functional grouping of birds

We generated 1000 trees based on “Hackett All Species” backbone, because it uses a more extensive genomic scope of loci in the phylogeny construction (Jetz et al., 2012; Ke et al., 2018). We applied the Maximum Clade Credibility Tree analysis (MCCT, programme “BEAST 2”, Bouckaert et al., 2014) to reduce the 1000 subset trees to one tree that had maximal phylogenetic support. We used eight functional traits, namely body mass, body length, culmen, tail, tarsus and wing length (morphometric traits), clutch size (reproductive trait) and foraging guilds (Table 1; Appendix I). Some bird species were falling in more than one foraging guild and were assigned to more than one group using 1 to indicate presence in a group and a 0 for absence (Table 1 Sekercioglu, 2006; Suri et al., 2017; Weideman et al., 2019). The foraging guilds are defined in Table 1.

2.4. Phylogenetic and functional α -diversity

To estimate phylogenetic diversity (PD), we used phylogeny of the world's birds (Jetz et al., 2012). Phylogenetic alpha diversity was calculated using Faith's PD (Faith, 1992). We used the function *pd* in the *picante* package in R (Kembel et al., 2010). Phylogenetic diversity (PD) measures the relatedness of species in evolutionary terms across community clades (Hensley et al., 2019).

We calculated the FD and equivalent PD for each sampling point using a directly related method to Faith's PD (Petchev & Gaston, 2002). First a trait matrix was used to create a distance matrix using the *gowdis*

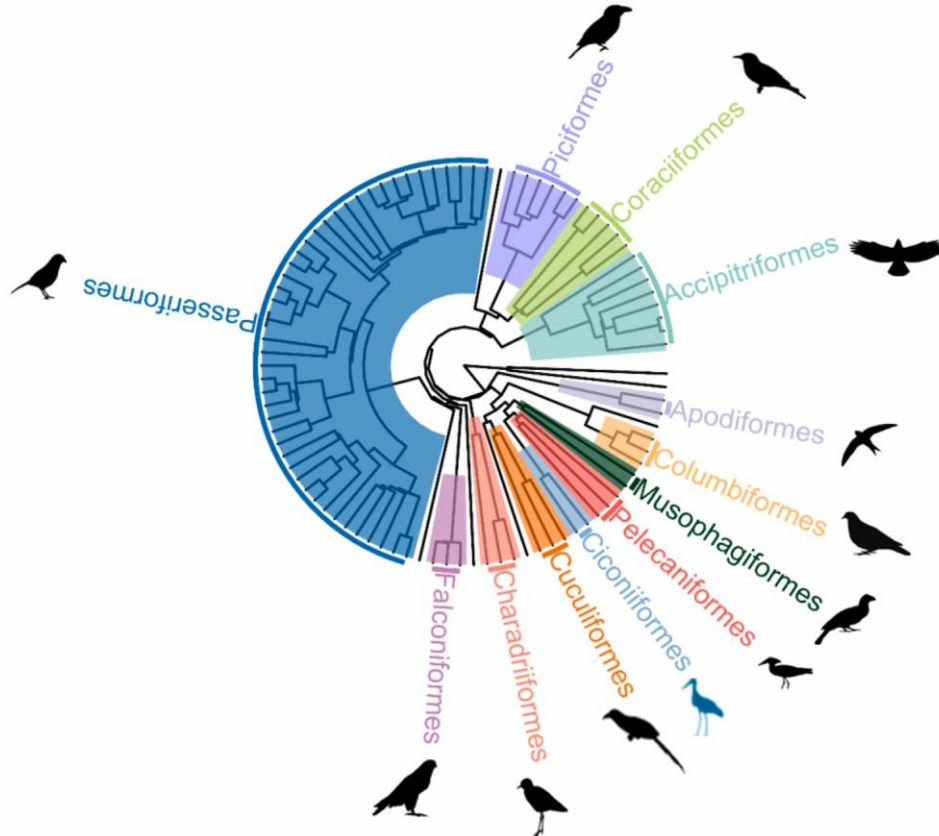


Fig. 2. Phylogeny of the 93 bird species that were recorded in this study. The tree was pruned from the most comprehensive dated phylogeny for birds (Hackett all species) backbone (Jetz et al., 2012). Taxonomic orders of birds with more than two species were highlighted in different colors. Bird silhouettes were downloaded from phylopic.org on 20 July 2020.

function in FD package. A dendrogram that represents similarity/dissimilarity of species according to their traits was then constructed from the distance matrix (Swenson, 2014). The dendrogram was then transformed into a phylogenetic object and the PD function was applied in the *picante* package in order to calculate the FD (Swenson, 2014). We calculated alpha functional diversity (FD) using the function *pd* in *picante* on the phylogenetic object obtained from the dendrogram.

Because of the high correlation between species richness and the measures of phylogenetic and functional diversity, we applied null models to assess the extent to which communities are over- or under-dispersed. We generated null distributions of phylogenetic and functional diversity indices for each site by shuffling the full species by site community matrix of all species found in the study area 999 times maintaining species occurrence frequency and sample species richness. We compared the observed phylogenetic and functional diversity to the mean of the null distribution by calculating a standardized effect size (SES) using the following equation:

$$SES = \frac{\text{observed} - \text{mean}(\text{null})}{SD(\text{null})} \quad (1) \text{ with the observed PD or FD}$$

at a single site subtracting the mean of the PD or FD null distribution divided by the standard deviation of the PD or FD null distribution. Lower values of SES (<0) indicate phylogenetic clustering (i.e. co-occurring bird species are more closely related than expected by chance), whereas higher values (>0) indicate phylogenetic over dispersion (i.e. co-occurring bird species are less closely related than expected by chance).

2.5. Phylogenetic and functional β -diversity

In order to understand the contribution of our two study sites to regional species pool, we applied β -diversity analysis within and between the two study sites. For within site, β -diversity was compared between sampled points within a site (Harare and Chivero Park), and for between sites (Harare-Chivero Park), we compared all sampled points in one site to all the sampled points in the other site (Weideman et al., 2019). We calculated functional and phylogenetic β -diversity using the *betapart* package (Baselga & Orme, 2012; Baselga, 2010). The PhyloSor index was used to calculate phylogenetic beta

diversity (β_{PD}). It is similar to Sorenson's index, but substitutes the unique and shared species with unique and shared phylogenetic branch length and represents the amount of PD shared between sites. This was converted to a dissimilarity measure ($1 - \text{PhyloSor}$). The same procedure was used to calculate functional beta diversity (β_{FD}) but using the functional dendrogram instead of the phylogeny. Standardized effect sizes (SES) for β -diversity were calculated using the formula used for alpha diversity metrics.

2.6. Phylogenetic signal of morphometric, reproductive and feeding functional traits

We calculated phylogenetic signal of all the seven binary foraging guild traits using *D* (Fritz & Purvis, 2010), by scaling the observed sum of sister-clade differences with the mean values of the two expected Σ distributions as follows ($\Sigma \Sigma$ Fritz & Purvis, 2010): $D = [d_{obs} - \text{mean}(\Sigma d_b)] / [\text{mean}(\Sigma d_r) - \text{mean}(\Sigma d_b)]$, where d_{obs} is the observed sum of sister-clade differences, Σd_b is the sum expected under Brownian evolution and Σd_r are the sum of sister-clade differences expected for a

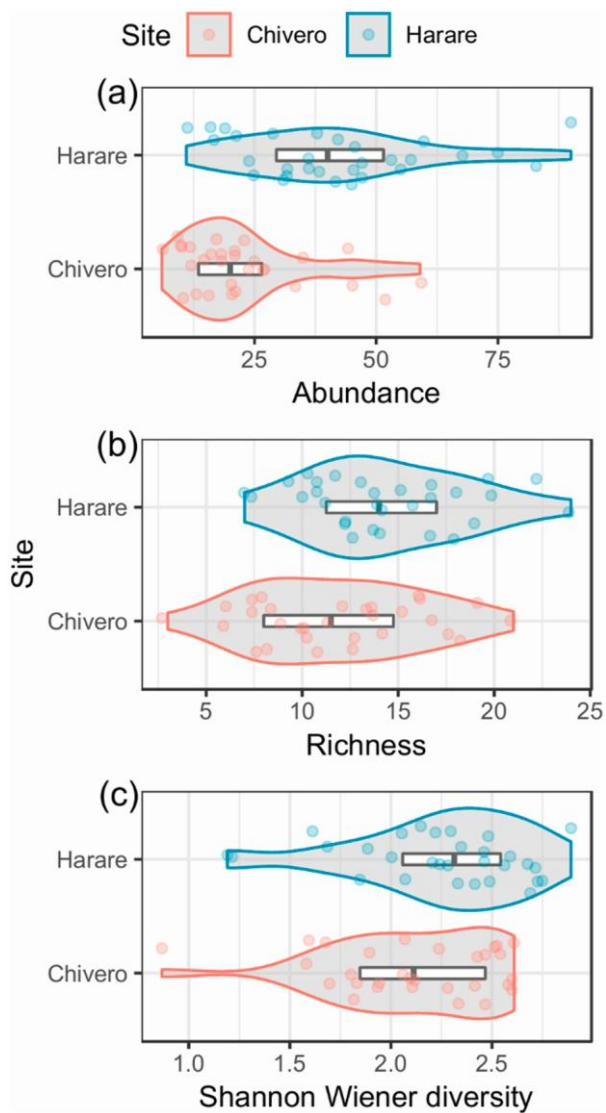


Fig. 3. Violin plots comparing bird species abundance, richness and Shannon Wiener index at sampled points between Harare and Chivero. Box of the boxplot inside the violins indicate 25%-quartile, median and 75%-quartile from left to right.

random phylogenetic pattern. Phylogenetic signal of continuous traits was calculated using Blomberg's K (Blomberg, Garland, & Ives, 2003) in *picante* package (Kembel et al., 2010).

2.7. Statistical analyses

Data were tested for normality and homogeneity of variance before analysis. Alpha diversity metrics (species richness, species abundance, Shannon Wiener index, PD, and FD) were compared between Harare and Chivero Park using independent t -test. One-way analysis of variance (ANOVA) was applied to test for variation in functional and phylogenetic beta-diversity metrics together with the respective standardized effect size (SES). Significant tests were further subjected to a Tukey Honest Difference Test (TukeyHSD) when p -value was < 0.05 . One sample t -tests were applied to test if the standardized effect sizes were significantly different from null expectation of zero. False discovery rate for t -tests was controlled for following the procedure in Benjamin and Yekutieli (2001). Since birds were sampled using avian point count, we used Mantel's test to calculate patterns of spatial autocorrelation for Harare and Chivero separately. The Mantel test can be used to examine relationships between multivariate dissimilarity matrices and a matrix of their geographic positions, and determines spatial dependence at

different distance classes (Borcard, Gillet, & Legendre, 2011). The correlogram produces r coefficients between -1 and 1 , where 1 is completely spatially dependent and -1 spatially independent.

3. Results

A total of 18 bird orders, 48 families, and 93 species were recorded at the two study sites (Fig. 2). Species richness for Chivero Park (72) was greater than that for Harare (66), with 27 and 21 species being unique to each site, respectively. Bird abundance was significantly higher ($W = 172$, $p < 0.0001$) per sampling point in Harare compared with Chivero (Fig. 3a). Species richness per sampling point was also significantly higher ($t = -2.26$, $df = 57.85$, $p = 0.027$) in Harare compared with Chivero (Fig. 3b). Although species richness and abundance per sampling point were higher in Harare compared with Chivero, Shannon Wiener index per sampling point did not vary significantly between the two sites ($W = 361$, $p = 0.19$) (Fig. 3c).

The most bird rich order was Passeriformes, containing almost half of all the species that were recorded (Fig. 2). Harare and Chivero had each two unique bird orders, Apodiformes and Coliiformes and Psittaciformes and Gruiformes, respectively (Appendices B and C). Passeriformes constituted more than half of the species that were occurring in Harare urban green spaces. The relative species richness in the different functional groups for Harare and Chivero Park were similar to those recorded at national and regional level ($\chi^2 = 29.056$, $df = 24$, p -value = 0.218 , Appendix D).

Phylogenetic diversity was significantly higher ($t = -2.13$, $df = 56.42$, $p = 0.038$) in Harare than Chivero (Fig. 4a). Similarly, Harare had significantly higher FD ($t = -3.51$, $df = 57.98$, $p < 0.001$) than Chivero (Fig. 4b). There was no significant difference in SES_{PD} ($t = 0.2252$, $df = 55.517$, p -value = 0.8226) and SES_{FD} ($t = -1.7504$, $df = 57.153$, p -value = 0.08541) between Harare and Chivero (Fig. 4 c & d, respectively).

3.1. Phylogenetic and functional beta diversity There was a significant difference ($F_{2,2637} = 398.2$, $p < 0.0001$) in β_{PD} between Harare, Chivero and Harare-Chivero. A posthoc test showed that Harare-Chivero beta-diversity was higher than that for both Chivero and Harare (Fig. 5a). Functional beta diversity varied significantly

($F_{2,2637} = 536.3$, $p < 0.0001$) between, Harare, Chivero and Harare-Chivero. A posthoc test showed that Harare-Chivero beta-diversity was higher than that for both Chivero and Harare (Fig. 5b). The standardized effect size for phylogenetic beta-diversity ($SES_{\beta_{PD}}$) varied significantly ($F_{2,2637} = 464.3$, $p < 0.0001$). Posthoc test showed that Chivero, Harare and Harare-chivero were all different (Fig. 5c). Harare-Chivero had significantly higher standardized effect size for functional beta-diversity ($SES_{\beta_{FD}}$) across sites ($F_{2,2637} = 528.6$, $p < 0.0001$; Fig. 5d).

3.2. Phylogenetic signal

All the bird feeding guilds did not differ significantly from the Brownian expectation ($D = 0$), except for nectarivores. Even those that differed significantly from the random expectation such as insectivores and raptors, they did not differ significantly from the Brownian expectation (Table 2). Only nectarivores differed significantly from the Brownian expectation (Table 2). All continuous traits showed a phylogenetic signal (Table 2).

3.3. Spatial autocorrelation
The test results for both Harare and Chivero are non-significant ($r = 0.016$, $p = 0.383$; $r = 0.017$, $p = 0.399$, respectively), leading to the conclusion that closer samples are not more similar.

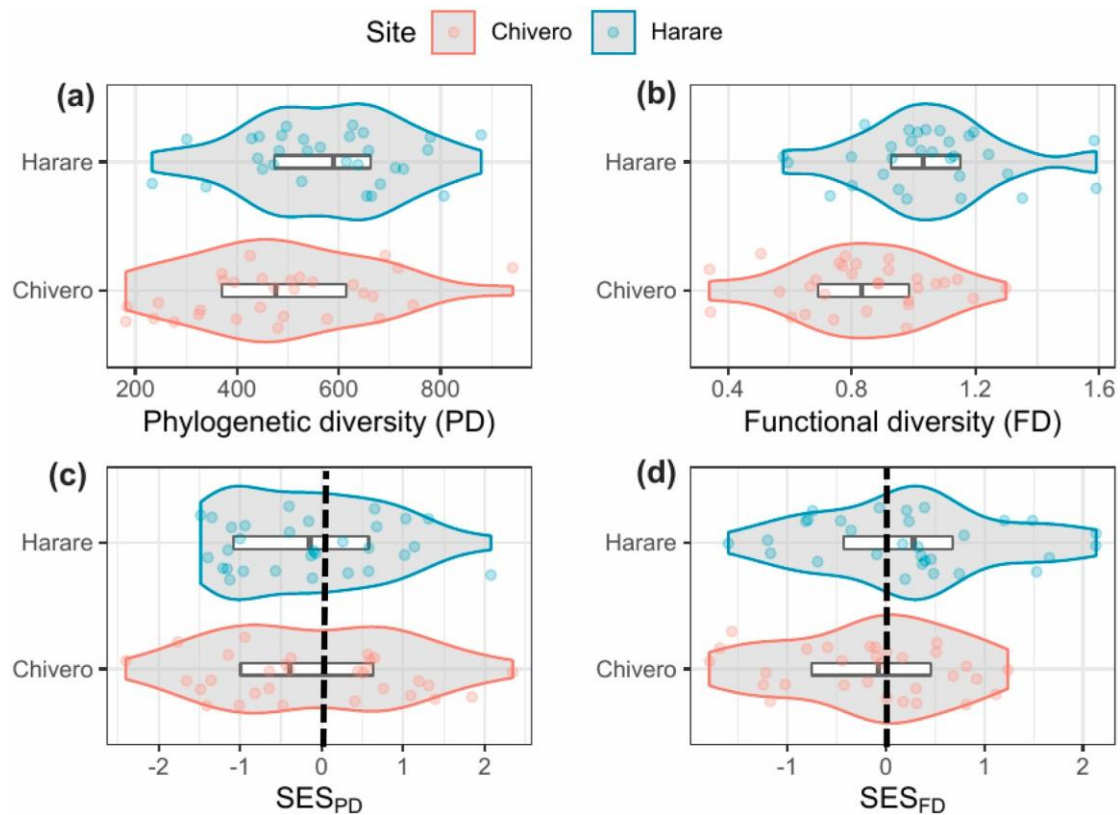


Fig. 4. Violin plots comparing bird species phylogenetic diversity (PD), Functional diversity (FD), standardized effect size for PD (SES_{PD}) and standardized effect size for FD (SES_{FD}) between Harare and Chivero. Box of the boxplot inside the violins indicate 25%-quartile, median and 75%-quartile from left to right.

4. Discussion

Our expectation that Chivero Park has higher bird species richness, abundance, phylogenetic and functional diversity than Harare was not supported. Although not significantly different, our results largely indicate that at beta scale bird functional diversity was higher in Harare while no difference was recorded for phylogenetic diversity between the two sites. Two bird orders were unique to each site, Apodiformes [Little Swift (*Apus affinis*) and African Palm-Swift (*Cypsiurus parvus*) urban specialists] and one species under Coliiformes, the Speckled Mouse-bird (*Colius striatus*) were unique to Harare, while Psittaciformes Meyer's Parrot (*Poicephalus meyeri*) and Gruiformes Black crane (*Amaurornis flavirostra*) a water bird were only occurring at Chivero Park. Proportional species richness for the different foraging groups did not differ between our two study sites, and between these two sites and those at national and regional level. The higher species abundance and richness in the urban green spaces observed here is similar to what was observed in suburban sites in Finland and Canada compared to periurban (Clergeau, Jokimaki, & Savard, 2001). Clergeau et al. (2001) attributed their observations to their study site being in the far north and supplementation of seeds at feeders in urban areas increasing seed eating bird richness. However, increasing species richness or abundance in urban areas could also increase their risks to certain threats such as predation by feral cats or collisions with windows (Loss, Will, & Marra, 2013; Seymour et al., 2020; Trouwborst, McCormack, & Martínez Camacho, 2020; van Doren et al., 2021). So, there are likely tradeoffs that take place in making urban areas more attractive to birds.

Our findings suggest that future urban developments should endeavour to leave patches of green spaces with native vegetation, establish urban gardens and golf courses within the urban landscape matrix. This suggestion stems from the fact that both FD and PD were high in Harare compared with Chivero Park. Also, Harare had higher species richness per sampling point than Chivero Park. Similarly, the urban matrix had higher FD, PD and species richness than Kruger National Park in a study from South Africa (Weideman et al., 2019). Indeed, our findings for FD and PD supports previous studies that

observed the significance of preserving urban green spaces in urban development as a way to promote biodiversity (Aronson et al., 2017; Lepczyk, Sorte, et al., 2017). Although our current study and that of Weideman et al. (2019) have shown higher phylogenetic and functional diversity in urban green spaces compared with nearby protected areas, this observation is contradictory to studies that have shown urbanization to be associated with lower phylogenetic diversity (Ibañez-Alamo et al., 2017; La Sorte et al., 2018), and differences could have emanated from differences in scales at which these studies have been carried out, local and global, respectively.

However, after controlling for species richness, phylogenetic diversity (SES_{PD}) of bird communities although not significantly different from zero, there was a tendency towards biological homogenization in both Harare and Chivero. This observation indicates that sampled points within each site comprised of phylogenetically related species. Indeed, urban environments have been previously reported to suffer from biotic homogenization in some previous studies (Clavel, Julliard, & Devictor, 2011; Godet, Güzere, Jiguet, & Devictor, 2015; Reif et al., 2013; Weideman et al., 2019).

The higher FD in Harare than Chivero Park suggests that birds recorded at sampling points in Harare are distributed across a wider range of functional clades than those recorded in Chivero Park. The likely reason why higher functional diversity was recorded in Harare is that it had more large bodied species (*Ciconia abdimii*, *Threskiornis aethiopicus*, *Falco amurensis*, *Numida meleagris*, *Bubulcus ibis* and *Columba livia*) and more lineages of generalist species that have adapted to living in highly urbanized environments for example Little Swift, African Palm-Swift and Pied Crow and these species were occurring in high numbers (Clavel et al., 2011; Suri et al., 2017). Indeed, Harare had more birds in the order Passeriformes which could have further enhanced

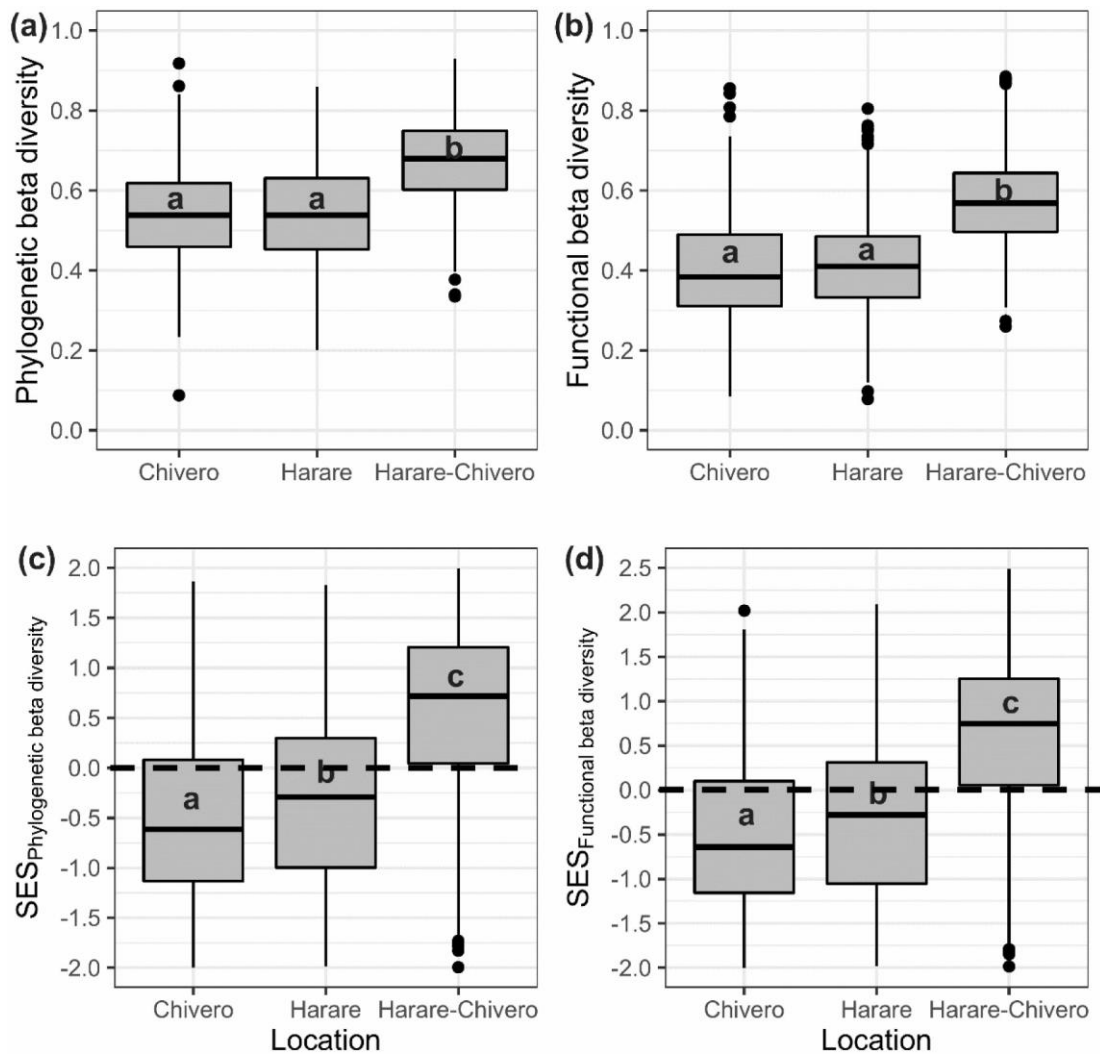


Fig. 5. Box plots comparing phylogenetic beta diversity (a), Functional beta diversity (b), standardized effect size for phylogenetic beta diversity (c) and standardized effect size for functional beta diversity (d) within sites (Harare and Chivero) and between sites (Harare-Chivero). The boxplot indicate 25%-quartile, median and 75%-quartile from bottom going up. The whiskers represent $1.5 \times$ interquartile range (bottom) and $1.5 \times$ interquartile range (top).

Table 2

Phylogenetic signal for seven bird foraging traits that we considered in this study. Values of D smaller than 0 are phylogenetically more conserved than under the Brownian model and values of D greater than 1 are phylogenetically over dispersed.

Categorical traits	Bird feeding guilds	D statistic	p-value
	Insectivores	0.08	< 0.01
	Frugivores	0.12	<0.01
	Granivores	- 0.46	<0.01
	Raptors	- 0.30	< 0.01
	Nectarivores	1.11	0.60
	Scavengers	- 0.14	0.06
	Grazers	0.44	0.12
Continuous variables	Continuous trait	Blomberg's K	p-value
	Body mass	3.46	0.001
	Body length	3.31	0.001
	Tarsus length	2.29	0.001
	Wing length	3.13	0.001

Culmen length	1.58	0.001
Tail length	1.63	0.001
Clutch size	0.40	0.002

functional diversity since they as well fall in several foraging guilds. The dominance of passerines in urban environments has been observed before (La Sorte et al., 2018). Furthermore, the high habitat diversity surrounding the sampled green spaces may enhance functional diversity and help explain this enigma (Hagen, Hagen, Ibañez-alamo, Petchey, & Evans, 2017; Mbiba et al., 2021). Relative to native species, the abundance of non-native species in urban areas tends to be higher (Lepczyk, Sorte, et al., 2017). After controlling for species richness, species in Harare are over dispersed, while in Chivero they are random. The over dispersion of bird functions in Harare is different from a similar study (Weideman et al., 2019), where clustering was observed in the urban environment. However, recent evidence suggests that higher functional diversity may result from higher rates of lineage turnover rather than speciation (Igea & Tanentzap, 2020). All the birds that were recorded in the urban green spaces were IUCN Red List least concern designates, which may still mean that a lot more still needs to be done in order to create conducive habitats for such species here. Alternatively, conservation of threatened species can be enforced outside of urban landscapes through law and policy.

Between sites (Harare-Chivero) beta diversity for both functional and phylogenetic diversity was higher compared to within sites (Harare and

Chivero). This high turnover in species between the two sites may indicate that urban landscapes produce sufficient heterogeneity that can be important for bird species conservation complementing the protected area matrix leading to higher regional bird diversity (Child, Cumming, & Amano, 2009; Fahrig, Arroyo-Rodríguez, Bennett, Boucher-Lalonde, Cazetta, Currie, & Watling, 2019; Ke et al., 2018; La Sorte et al., 2018). After controlling for species richness, functional and phylogenetic β -diversity showed over dispersion between sites (Harare-Chivero). The fact that Chivero Park sampling points were clustered compared with those from Harare for β -diversity is different from what was observed in South Africa where the protected area had higher diversity compared with the urban environment (Weideman et al., 2019). There was evidence of biotic homogenization of β -diversity within sites for both phylogenetic and functional diversity, and this is only similar to other studies that were carried in the urban environments (Ibañez-Alamo et al., 2017; Weideman et al., 2019). Differences probably emanated from our small sample size which was not repeated across years. We therefore, ask people to interpret our results with caution.

Our study uses a protected area located near a city to assess how urban green spaces influence phylogenetic and functional diversity of breeding bird assemblages. We show that urban green spaces have the potential to maintain high species richness, abundance, functional and phylogenetic diversity. However, on the other hand protected areas may exhibit functional redundancy and broad-based clade diversity for phylogenetic diversity. Overall, urban green spaces can complement protected areas, thereby improving the national and regional functional and phylogenetic diversity. Although all the functional groups were represented in the urban green spaces as well as in Lake Chivero Park, this study did not record any bird species designated of significant concern in the IUCN Red List.

Funding

Not applicable.

Data availability statement

Upon Acceptance data will be made available from the Dryad Digital Repository.

Acknowledgements

We would like to thank our field assistant Innocent Magunje for his dedication to the project during data collection. The authors are indebted to the reviewers for their time and effort that allowed us to increase the clarity and quality of our work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2022.104462>.

References

- Armson, D., Stringer, P., & Ennos, A. R. (2013). Urban forestry & urban greening the effect of street trees and amenity grass on urban surface water runoff in. *Urban Forestry & Urban Greening*, 12(3), 282–286. <https://doi.org/10.1016/j.ufug.2013.04.001>
- Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., ... Winter, M. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B: Biological Sciences*, 281(1780). <https://doi.org/10.1098/rspb.2013.3330>
- Aronson, M. F. J., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., Macivor, J. S., ... Vargo, T. (2017). Biodiversity in the city: Key challenges for urban green space management. *Frontiers in Ecology and the Environment*, 15, 189–196. <https://doi.org/10.1002/fee.1480>
- Baselga, A. (2010). Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography*, 19(1), 134–143. <https://doi.org/10.1111/j.1466-8238.2009.00490.x>
- Baselga, A., & Orme, C. D. L. (2012). Betapart: An R package for the study of beta diversity. *Methods in Ecology and Evolution*, 3(5), 808–812. <https://doi.org/10.1111/j.2101-210X.2012.00224.x>
- Benjamin, Y., & Yekutieli, D. (2001). The control of the false discovery rate in multiple testing under dependency. *The Annals of Statistics*, 29(4), 1165–1188.
- Blomberg, S. P., Garland, T., & Ives, A. R. (2003). Testing for phylogenetic signal in comparative data: Behavioral traits are more labile. *Evolution*, 57(4), 717–745. <https://doi.org/10.1111/j.0014-3820.2003.tb00285.x>
- Borcard, D., Gillet, F., & Legendre, P. (2011). *Numerical ecology with R*. New York, NY, US.: Springer.
- Bouckaert, R., Heled, J., Kühnert, D., Vaughan, T., Wu, C. H., Xie, D., ... Drummond, A. J. (2014). BEAST 2: A software platform for bayesian evolutionary analysis. *PLoS Computational Biology*, 10(4), 1–6. <https://doi.org/10.1371/journal.pcbi.1003537>
- Bregman, T. P., Lees, A. C., MacGregor, H. E. A., Darski, B., de Moura, N. G., Aleixo, A., ... Tobias, J. A. (2016). Using avian functional traits to assess the impact of land-cover change on ecosystem processes linked to resilience in tropical forests. *Proceedings of the Royal Society B: Biological Sciences*, 283(1844). <https://doi.org/10.1098/rspb.2016.1289>
- Cadotte, M., Carscadden, K., & Mirotnick, N. (2011). Beyond species: Functional diversity and the maintenance of ecological processes and services. *Journal of Applied Ecology*, 48(5), 1079–1087. <https://doi.org/10.1111/j.1365-2664.2011.02048.x>
- Cadotte, M. W., Dinnage, R., & Tilman, D. (2012). Phylogenetic diversity promotes ecosystem stability. *Ecology*, 93(8 SPEC. ISSUE), 223–233. <https://doi.org/10.1890/11-0426.1>
- Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: A review. *Landscape and Urban Planning*, 74(1), 46–69. <https://doi.org/10.1016/j.landurbplan.2004.08.007>
- Chapman, P. M., Tobias, J. A., Edwards, D. P., & Davies, R. G. (2018). Contrasting impacts of land-use change on phylogenetic and functional diversity of tropical forest birds. *Journal of Applied Ecology*, 55(4), 1604–1614. <https://doi.org/10.1111/1365-2664.13073>
- Child, M. F., Cumming, G. S., & Amano, T. (2009). Assessing the broad-scale impact of agriculturally transformed and protected area landscapes on avian taxonomic and functional richness. *Biological Conservation*, 142(11), 2593–2601. <https://doi.org/10.1016/j.biocon.2009.06.007>
- Clavel, J., Julliard, R., & Devictor, V. (2011). Worldwide decline of specialist species: Toward a global functional homogenization? *Frontiers in Ecology and the Environment*, 9(4), 222–228. <https://doi.org/10.1890/080216>
- Clergeau, P., Croci, S., Jokimaki, J., Kaisanlahti-Jokimäki, M. L., & Dinetti, M. (2006). Avifauna homogenisation by urbanisation: Analysis at different European latitudes. *Biological Conservation*, 127(3), 336–344. <https://doi.org/10.1016/j.biocon.2005.06.035>
- Clergeau, P., Jokimaki, J., & Savard, J. P. L. (2001). Are urban bird communities influenced by the bird diversity of adjacent landscapes? *Journal of Applied Ecology*, 38(5), 1122–1134. <https://doi.org/10.1046/j.1365-2664.2001.00666.x>
- Edwards, D. P., Magrath, A., Woodcock, P., Ji, Y., Norman, T., Edwards, F. A., ... Yu, D. W. (2014). Selective-logging and oil palm: Multitaxon impacts, biodiversity indicators, and trade-offs for conservation planning. *Ecological Applications*, 24(8), 2029–2049.
- Evans, K. L., Newson, S. E., & Gaston, K. J. (2009). Habitat influences on urban avian assemblages. *Ibis*, 151(1), 19–39. <https://doi.org/10.1111/j.1474-919X.2008.00898.x>
- Fahrig, L., Arroyo-Rodríguez, V., Bennett, J. R., Boucher-Lalonde, V., Cazetta, E., Currie, D. J., ... Watling, J. I. (2019). Is habitat fragmentation bad for biodiversity? *Biological Conservation*, 230(December 2018), 179–186. <https://doi.org/10.1016/j.biocon.2018.12.026>
- Faith, D. P. (1992). Conservation evaluation and phylogenetic diversity. *Biological Conservation*, 61, 1–10. [https://doi.org/10.1890/0012-9658\(2006\)87\[1465:ATTFHF\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2006)87[1465:ATTFHF]2.0.CO;2)
- Fontana, S., Sattler, T., Bontadina, F., & Moretti, M. (2011). How to manage the urban green to improve bird diversity and community structure. *Landscape and Urban Planning*, 101(3), 278–285. <https://doi.org/10.1016/j.landurbplan.2011.02.033>
- Fritz, S. A., & Purvis, A. (2010). Selectivity in mammalian extinction risk and threat types: A new measure of phylogenetic signal strength in binary traits. *Conservation Biology*, 24(4), 1042–1051. <https://doi.org/10.1111/j.1523-1739.2010.01455.x>
- Garaffa, P. I., Filloy, J., & Bellocq, M. I. (2009). Bird community responses along urban-rural gradients: Does the size of the urbanized area matter? *Landscape and Urban Planning*, 90(1–2), 33–41. <https://doi.org/10.1016/j.landurbplan.2008.10.004>
- Godet, L., Güzere, P., Jiguet, F., & Devictor, V. (2015). Dissociating several forms of commonness in birds sheds new light on biotic homogenization. *Global Ecology and Biogeography*, 24(4), 416–426. <https://doi.org/10.1111/geb.12266>
- Hackett, S. J., Kimball, R. T., Reddy, S., Bowie, R. C. K., Braun, E. L., Braun, M. J., ... Yuri, T. (2008). A phylogenomic study of birds reveals their evolutionary history. *Science*, 320(5884), 1763–1768. <https://doi.org/10.1126/science.1157704>
- Hagen, E. O., Hagen, O., Ibañez-Alamo, J. D., Petchey, O. L., & Evans, K. L. (2017). Impacts of urban areas and their characteristics on avian functional diversity. *Frontiers in Ecology and Evolution*, 5(JUL), 1–15. <https://doi.org/10.3389/fevo.2017.00084>
- Hensley, C. B., Trisos, C. H., Warren, P. S., MacFarland, J., Blumenshine, S., Reece, J., & Katti, M. (2019). Effects of urbanization on native bird species in three southwestern US cities. *Frontiers in Ecology and Evolution*, 7(MAR), 1–10. <https://doi.org/10.3389/fevo.2019.00071>
- Hughes, E. C., Edwards, D. P., Sayer, C. A., Martin, P. A., & Thomas, G. H. (2020). The effects of tropical secondary forest regeneration on avian phylogenetic diversity. *Journal of Applied Ecology*, 1–12. <https://doi.org/10.1111/1365-2664.13639>

- Ibañez-Alamo, J. D., Rubio, E., Benedetti, Y., & Morelli, F. (2017). Global loss of avian evolutionary uniqueness in urban areas. *Global Change Biology*, 23(8), 2990–2998. <https://doi.org/10.1111/gcb.13567>
- Igea, J., & Tanentzap, A. J. (2020). Angiosperm speciation cools down in the tropics. *Ecology Letters*, 23(4), 692–700. <https://doi.org/10.1111/ele.13476> IUCN. (2011). IUCN red list of threatened species.
- Ives, C. D., Lentini, P. E., Threlfall, C. G., Ikin, K., Shanahan, D. F., Garrard, G. E., ... Kendal, D. (2016). Cities are hotspots for threatened species. *Global Ecology and Biogeography*, 25(1), 117–126. <https://doi.org/10.1111/geb.12404>
- Jarzyna, M. A., & Jetz, W. (2016). Detecting the multiple facets of biodiversity. *Trends in Ecology and Evolution*, 31(7), 527–538. <https://doi.org/10.1016/j.tree.2016.04.002>
- Jetz, W., Thomas, G. H., Joy, J. B., Hartmann, K., & Mooers, A. O. (2012). The global diversity of birds in space and time. *Nature*, 491(7424), 444–448. <https://doi.org/10.1038/nature11631>
- Ke, A., Sibiya, M. D., Reynolds, C., McCleery, R. A., Monadjem, A., & Fletcher, R. J. (2018). Landscape heterogeneity shapes taxonomic diversity of non-breeding birds across fragmented savanna landscapes. *Biodiversity and Conservation*, 27(10), 2681–2698. <https://doi.org/10.1007/s10531-018-1561-7>
- Kembel, S. W., Cowan, P. D., Helmus, M. R., Cornwell, W. K., Morlon, H., Ackerly, D. D., ... Webb, C. O. (2010). Picante: R tools for integrating phylogenies and ecology. *Bioinformatics*, 26(11), 1463–1464. <https://doi.org/10.1093/bioinformatics/btq166>
- La Sorte, F. A., Lepczyk, C. A., Aronson, M. F. J., Goddard, M. A., Hedblom, M., Katti, M., ... Yang, J. (2018). The phylogenetic and functional diversity of regional breeding bird assemblages is reduced and constricted through urbanization. *Diversity and Distributions*, 24(7), 928–938. <https://doi.org/10.1111/ddi.12738>
- Lepczyk, C. A., Aronson, M. F. J., Evans, K. L., Goddard, M. A., Lerman, S. B., & Macivor, J. S. (2017). Biodiversity in the city: Fundamental questions for understanding the ecology of urban green spaces for biodiversity conservation. *BioScience*, 67(9), 799–807. <https://doi.org/10.1093/biosci/bix079>
- Lepczyk, C. A., Sorte, F. A., La, Aronson, M. F. J., Goddard, M. A., MacGregor-Fors, I., Nilon, C. H., & Warren, P. S. (2017). Global patterns and drivers of urban bird diversity. In E. Murgui & M. Hedblom (Eds.), *Ecology and Conservation of Birds in Urban Environments* (pp. 13–33). Springer International Publishing. <https://doi.org/10.1007/978-3-319-43314-1>.
- Lepczyk, C. A., Flather, C. H., Radeloff, V. C., Pidgeon, A. M., Hammer, R. B., & Liu, J. (2008). Human impacts on regional avian diversity and abundance. *Conservation Biology*, 22(2), 405–416. <https://doi.org/10.1111/j.1523-1739.2008.00881.x>
- Lopez, B. E., Burgio, K. R., Carlucci, M. B., Palmquist, K. A., Parada, A., Weinberger, V. P., & Hurlbert, A. H. (2016). A new framework for inferring community assembly processes using phylogenetic information, relevant traits and environmental gradients. *One Ecosystem*, 1, 1–24. <https://doi.org/10.3897/oneeco.1.e9501>
- Loss, S. R., Will, T., & Marra, P. P. (2013). The impact of free-ranging domestic cats on wildlife of the United States. *Nature Communications*, 4. <https://doi.org/10.1038/ncomms2380>
- Mbiba, M., Mazhude, C., Fabricius, C., Fritz, H., & Muvengwi, J. (2021). Bird species assemblages differ, while functional richness is maintained across an urban landscape. *Landscape and Urban Planning*, 212. <https://doi.org/10.1016/j.landurbplan.2021.104094>
- McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, 127(3), 247–260. <https://doi.org/10.1016/j.biocon.2005.09.005>
- Morelli, F., Benedetti, Y., Ibañez-Alamo, J. D., Jokimaki, J., Mand, R., Tryjanowski, P., & Moller, A. P. (2016). Evidence of evolutionary homogenization of bird communities in urban environments across Europe. *Global Ecology and Biogeography*, 1–10. <https://doi.org/10.1111/geb.12486>
- Muvengwi, J., Kwenda, A., Mbiba, M., & Mpindu, T. (2019). The role of urban schools in biodiversity conservation across an urban landscape. *Urban Forestry and Urban Greening*, 43, Article 126370. <https://doi.org/10.1016/j.ufug.2019.126370>
- Pautasso, M., Bohning-Gaese, K., Clergeau, P., Cueto, V. R., Dinetti, M., Fernández Juricic, E., ... Cantarello, E. (2011). Global macroecology of bird assemblages in urbanized and semi-natural ecosystems. *Global Ecology and Biogeography*, 20(3), 426–436. <https://doi.org/10.1111/j.1466-8238.2010.00616.x>
- Petchey, O. L., & Gaston, K. J. (2002). Functional diversity (FD), species richness and community composition. *Ecology Letters*, 5, 402–411.
- Petchey, O. L., & Gaston, K. J. (2006). Functional diversity: Back to basics and looking forward. *Ecology Letters*, 9(6), 741–758. <https://doi.org/10.1111/j.1461-0248.2006.00924.x>
- Reif, J., Prylova, K., Sizing, A. L., Vermouzek, Z., Šaštný, K., & Bejček, V. (2013). Changes in bird community composition in the Czech Republic from 1982 to 2004: Increasing biotic homogenization, impacts of warming climate, but no trend in species richness. *Journal of Ornithology*, 154(2), 359–370. <https://doi.org/10.1007/s10336-012-0900-9>
- Sekercioglu, C. H. (2006). Increasing awareness of avian ecological function. *Trends in Ecology and Evolution*, 21(8), 464–471. <https://doi.org/10.1016/j.tree.2006.05.007>
- Seymour, C. L., Simmons, R. E., Morling, F., George, S. T., Peters, K., & O'Riain, M. J. (2020). Caught on camera: The impacts of urban domestic cats on wild prey in an African city and neighbouring protected areas. *Global Ecology and Conservation*, 23. <https://doi.org/10.1016/j.gecco.2020.e01198>
- Suri, J., Anderson, P. M., Charles-dominique, T., Hellard, E., & Cumming, G. S. (2017). Landscape and Urban Planning More than just a corridor: A suburban river catchment enhances bird functional diversity. *Landscape and Urban Planning*, 157, 331–342. <https://doi.org/10.1016/j.landurbplan.2016.07.013>
- Swenson, N. G. (2014). In *Functional and Phylogenetic Ecology*. New York Heidelberg Dordrecht London: Springer. <https://doi.org/10.1007/978-1-4614-9542-0>
- Threlfall, C. G., & Kendal, D. (2016). The distinct ecological and social roles that wild spaces play in urban ecosystems. *Urban Forestry and Urban Greening*. <https://doi.org/10.1016/j.ufug.2017.05.012>
- Trouwborst, A., McCormack, P. C., & Martínez Camacho, E. (2020). Domestic cats and their impacts on biodiversity: A blind spot in the application of nature conservation law. *People and Nature*, 2(1), 235–250. <https://doi.org/10.1002/pan3.10073>
- Vailshery, L. S., Jaganmohan, M., & Nagendra, H. (2013). Urban Forestry & Urban Greening Effect of street trees on microclimate and air pollution in a tropical city. *Urban Forestry & Urban Greening*, 12(3), 408–415. <https://doi.org/10.1016/j.ufug.2013.03.002>
- van Doren, B. M., Willard, D. E., Hennen, M., Horton, K. G., Stuber, E. F., Sheldon, D., ... Winger, B. M. (2021). Drivers of fatal bird collisions in an urban center. *Proceedings of the National Academy of Sciences of the United States of America*, 118(24). <https://doi.org/10.1073/pnas.2101666118>
- van Rensburg, B. J., Peacock, D. S., & Robertson, M. P. (2009). Biotic homogenization and alien bird species along an urban gradient in South Africa. *Landscape and Urban Planning*, 92(3–4), 233–241. <https://doi.org/10.1016/j.landurbplan.2009.05.002>
- Venail, P., Gross, K., Oakley, T. H., Narwani, A., Allan, E., Flombaum, P., ... Cardinale, B. J. (2015). Species richness, but not phylogenetic diversity, influences community biomass production and temporal stability in a re-examination of 16 grassland biodiversity studies. *Functional Ecology*, 29(5), 615–626. <https://doi.org/10.1111/1365-2435.12432>
- Weideman, E. A., Slingsby, J. A., Thomson, R. L., & Coetzee, B. T. W. (2019). Land cover change homogenizes functional and phylogenetic diversity within and among African savanna bird assemblages. *Landscape Ecology*, 0123456789. <https://doi.org/10.1007/s10980-019-00939-z>
- Wenny, D. G., DeVault, T. L., Johnson, M. D., Kelly, D., Sekercioglu, C. H., Tomback, D. F., & Whelan, C. J. (2011). Perspectives in ornithology the need to quantify ecosystem services provided by birds. *Auk*, 128(1), 1–14. <https://doi.org/10.1525/auk.2011.10248>
- Yang, J., McBride, J., Zhou, J., & Sun, Z. (2004). The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry and Urban Greening*, 3(2), 65–78. <https://doi.org/10.1016/j.ufug.2004.09.001>