

A continuous urbanization index to assess phylogenetic adaptations in urban bird living

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ABSTRACT

<https://www.youtube.com/watch?v=9Gc4QTqslN4>

INTRODUCTION

Urbanization fragments and isolates natural habitat (Marzluff & Ewing, 2001; Melles *et al.*, 2003; Loram *et al.*, 2007), drastically altering species' composition and ecosystem functions. Thus, urbanization globally threatens biodiversity through processes such as biotic homogenization (McKinney, 2006, 2008) and is a major threat to conservation (Czech *et al.*, 2000; Dearborn & Kark, 2010). Despite the documented loss of biodiversity directly or indirectly caused by urbanization (McKinney & Lockwood, 1999; McKinney, 2006; Devictor *et al.*, 2007), some species have successfully adapted to, colonized, and subsequently thrived in urban environments (McKinney, 2002; Chace & Walsh, 2006; Lowry *et al.*, 2013; McDonnell & Hahs, 2015). For instance, some species which rarely occur within urban areas can be relatively common in surrounding rural habitats (Tratalos *et al.*, 2007; Evans *et al.*, 2011; Gatesire *et al.*, 2014).

In order to best predict species' responses to future urbanization changes, it is essential to understand what biological traits are associated with urban birds (e.g., McClure, 1989; Bonier *et al.*, 2007; Møller, 2009; McDonnell & Hahs, 2015). To date, a wide array of traits have been used to predict presence of birds in urban environments. For instance, degree of sociality (McClure, 1989; Coleman & Mellgren, 1994; Jokimäki & Suhonen, 1998), nesting substrate (Kark *et al.*, 2007; Croci *et al.*, 2008), diet (Beissinger & Osborne, 1982; Fuller *et al.*, 2008; Major & Parsons, 2010; Evans *et al.*, 2011), distribution size (Jokimäki & Huhta, 2000; Chace & Walsh, 2006; Croci *et al.*, 2008), migratory status (Friesen *et al.*, 1995), niche breadth (Kark *et al.*, 2007; Evans *et al.*, 2011), and fecundity (Croci *et al.*, 2008; Møller, 2009; Vaugoyeau *et al.*, 2016), among other traits (see Appendix 1), have all been hypothesized to influence a birds' presence in urban environments. Rather than a specific trait that predicts a species' ability to be found in urban environments, it is most likely a combination of traits. For instance, urban birds' presence in Jerusalem was predicted by a combination of traits including diet, degree of sociality, sedentariness, and preferred nesting sites (Kark *et al.*, 2007), while a regional analysis throughout France and Switzerland demonstrated that urban birds preferred forested habitats, were sedentary, omnivorous, high-nesters, and widely distributed

(Croci *et al.*, 2008). Notably, a wide range of results using the aforementioned traits have been reported in the literature, often contrasting one another. Indeed, brain size was found to be important by Møller and Erritzøe (2015) and Maklakov *et al.* (2011) but Evans *et al.* (2011) and Kark *et al.* (2007) found that brain size had no effect on species' response to urbanization. Similarly, contrasting results have been reported for annual fecundity (cf., Evans *et al.*, 2011 with Møller (2009) & Croci *et al.* (2008)) and generalism or niche breadth (cf., Kark *et al.*, 2007 with Evans *et al.* (2011)).

The majority of previous studies place species in discrete groups such as urban avoiders, adapters, or exploiters (e.g., McKinney, 2002, 2006; Kark *et al.*, 2007; McDonnell & Hahs, 2015) or even birds which do or do not occur within urban environments (e.g., Bonier *et al.*, 2007; Møller, 2009). This type of discrete response variable severely limits the generalization of these studies' results as it assumes species within a group respond to urbanization equally (Evans *et al.*, 2011). Moreover, the terminology (i.e., urban adapters, avoiders, and exploiters) is used differently among studies [cf., (Kark *et al.*, 2007) and (Croci *et al.*, 2008)], potentially affecting interpretation between scientists and the public (Fischer *et al.*, 2015; McDonnell & Hahs, 2015). In a notable exception, (Evans *et al.*, 2011) advocates for a continuous measure of urbanization in which a species' is assessed on their entire distribution in response to urban environments.

Despite the number of studies which have investigated the relationships between species' traits and urban adaptedness, most studies are either spatially limited, such as a single city or region (Blair, 1996; Kark *et al.*, 2007; Croci *et al.*, 2008); or temporally limited to a single breeding season (Blair, 1996) or even two month survey period (Kark *et al.*, 2007)]. Fortunately, citizen science (see reviews by Devictor *et al.*, 2010; Tulloch *et al.*, 2013; Bonney *et al.*, 2014; Kobori *et al.*, 2016) can provide broad-scale empirical datasets, allowing us to test hypotheses at spatial and temporal scales previously difficult to attain. This data provides a cost-effective method to research the relationship between species' traits and urban observations. Indeed, various projects have used citizen science data to elucidate information on abundance and distribution of birds in urban ecosystems (McCaffrey, 2005; Callaghan *et al.*, 2017), as well as functional composition of urban birds (La Sorte *et al.*, 2014; Morelli *et al.*, 2016; Lepczyk *et al.*, 2017). However, we unaware of any projects which use citizen science observations to assess species' traits in relation to urban environments over a large spatial and temporal scale.

Here, we improve upon current methods of assessing biological traits which predicts urbanization in birds by using a series of publicly available datasets available for Australian birds. Importantly, we developed and used a continuous urbanization index as a response variable in the analyses. We had two objectives. Our first objective was to investigate whether there was a phylogenetic signal in our urbanization index, as previous studies have found a lack of phylogenetic signal in urbanization (Evans *et al.*, 2011). Second, we developed models which were and were not phylogenetically constrained to assess species' traits that predict pre-adaptation to urban living, using continuous and categorical explanatory variables. These results are especially critical in the future action plans of Australia's birds (Garnett *et al.*, 2011), given Australia is currently undergoing a period of rapid urban growth.

METHODS

Study area

We looked at bird observations throughout the whole of continental Australia. Bird observations from outlying islands were eliminated from potential analyses.

Bird observation data

Bird observations originated from eBird (Sullivan *et al.*, 2009, 2014), a large-scale empirical dataset collected by citizen scientists. Volunteer birdwatchers submit lists of species seen or heard at a given location, over a user-determined duration and survey area (Wood *et al.*, 2011). We downloaded the eBird basic dataset (version ebd_relFeb-2018; available here: <https://ebird.org/data/download>), and used all observations between January 1, 2010 - February 28, 2018. This temporal scale was used because this is the period in which eBird data are richest and because this time period minimized undue leverage of mismatch between changes in the response variable measurement (see response variable below) over the given time frame in which bird observations were collected.

We filtered the bird observations (La Sorte *et al.*, 2014; Callaghan *et al.*, 2017) by only including observations which were on complete checklists and which followed these protocols: travelling, random, stationary, area, or BirdLife Australia protocols (Barrett *et al.*, 2003). For further information on protocols see here: <http://help.ebird.org/customer/portal/articles/1006209-understanding-observation-types>]. Further, we filtered the checklists to those with a distance travelled of < 5 km or an area covered which was < 500 Ha. Any checklists which were shared among multiple individuals were subsampled to include only one checklist in order to avoid duplicate results. After this sampling, we were left with 637,482 eligible checklists throughout Australia.

Seabirds (gannets, petrels, shearwaters, etc.) were omitted from the analyses as we did not expect any correlation with seabirds using urban areas under normal circumstances. Only species which included > 100 observations in the eBird database over the specified time-frame, and that met our criteria were considered for further analyses. This left us with 580 potential species from the eBird dataset which had > 100 observations on eligible checklists in the specified time frame.

Response variable - an urbanization index

We used VIIRS night-time lights (Elvidge *et al.*, 2017) as a proxy of a bird's association with urban habitat. The VIIRS night-time lights measures the electric lighting present on Earth's surface which is generally associated with human settlement. There are also a significant number of steps (e.g., filtering out background noise, degraded data, and other light source contamination) which are used to ensure the validity of the data and its association

with human settlement (Elvidge *et al.*, 2017). For the 637,482 checklists which met our criteria above, we used the checklists' associated spatial coordinates and Google Earth Engine (Gorelick *et al.*, 2017) to assign the average radiance value calculated from the VIIRS layer. For each location, the average radiance was calculated within a 5 km buffer, in order to match the spatial scale of the checklists included and to minimize any potential bias in eBird sampling protocols. Any radiance values which were negative were forced to 0.00001 (*sensu* Ou *et al.*, 2015).

Each checklist's average radiance value was then passed to every bird on that checklist, which provided every species with a distribution of average radiance values (Fig. 1). Our response variable, which served as an urbanization index, was the median for each species' given distribution of average radiance values.

Explanatory variables

Explanatory variables were calculated using a published dataset which contains the biological, ecological, and conservation information for all of Australia's birds (Garnett *et al.*, 2015). Potential traits were chosen on the basis of their existing support and hypotheses in the current literature (e.g., (McClure, 1989; Kark *et al.*, 2007; Evans *et al.*, 2011)). Traits were parsed in different manners, and for any missing value in the dataset, we treated that as evidence against it existing (i.e., if a species had NA for a specific habitat, we assumed that the lack of evidence found by the authors indicates that the species is unlikely to be found in that habitat). Appendix 1 provides an overview of all candidate traits, some associated references for each trait, and more detailed information on how the traits were calculated.

Only species which had complete data for the list of candidate traits were considered in the analyses.

Phylogenetic analysis

For the phylogenetic portion of our analyses, we used the phylogenetic tree provided by Jetz *et al.* (Jetz *et al.*, 2012). This phylogeny represents the first completely mapped phylogeny of 9,993 birds (Jetz *et al.*, 2012).

In order to assess whether there was a phylogenetic signal of the urbanization index used in our study, we used the phylosignal package (Keck *et al.*, 2016) in the R computing environment (R Core Team, 2017).

Taxonomic considerations

Given the diverse datasets used in this analysis, there were differing taxonomic authorities followed. The response data from eBird follows the eBird/clements checklist [<http://www.birds.cornell.edu/clementschecklist/>], while the biological and ecological data follows the working list of Australian birds by BirdLife Australia [<http://www.birdlife.org.au/>]

conservation/science/taxonomy], and the phylogenetic tree followed the BirdLife V3 world checklist [<http://birdtree.org/taxonomy/>]. There were minor differences which existed in common names, English names, and recognized species among the three datasets. A taxonomic key was made which combined the three different taxonomies (Appendix 2). Ultimately, a species' response variable, calculated from the eBird database and taxonomic source, was considered for analysis if it matched for both the trait dataset and the phylogenetic tree dataset. If it did not match both, then it was not considered for analysis (e.g., species currently only recognized by eBird/clements such as Western Whistler, Silver-backed Butcherbird, or Paperbark Flycatcher). Additionally, one species (Aleutian Tern) met the criteria for number of observations above, but was not included in the Australian trait data because it is new to Australia and thus not included in the analysis.

Models

Before modelling, the explanatory variables (Appendix 1) were investigated for collinearity, and brain size and body size were highly correlated. Due to the affect that collinearity can have on modelling (Cade, 2015), we were inclined to drop one of the two correlated explanatory variables. Given that others using a continuous response measure of urbanization have found brain size to have no evidence of species' response to urban environments (Evans *et al.*, 2011), we eliminated this trait from consideration. In so doing, it also increased the number of species to be included in our models.

We had two linear modelling approaches; one with and one without phylogenetic constraints. Our urbanization index was log-transformed in order to meet model assumptions. The explanatory variables used in the models were those listed in Appendix 1, with the exception of brain size.

For both approaches, we employed a model-averaging technique (Grueber *et al.*, 2011) in which we 'dredged' all possible subsets of the model (Barton, 2016). The global model was weighted by a measure of error associated with the response variable. This was assessed as the proportion of the number of total observations of a species divided by the number of unique localities a species was observed from. This helps to give more weight in the model-fitting procedure to those species that had more observations in more unique locations (i.e., an assessment of reliability of the observations). The global model fit was assessed by averaging the R2 values (Nakagawa & Schielzeth, 2013; Nakagawa *et al.*, 2017) for each model in the top-selected model-set. Additionally, we calculated the relative contribution of each explanatory variable (*sensu* Evans *et al.*, 2011) by **XXXXXXXXXXXXXXXXXXXX**. The phylogenetically constrained model was fit using the 'phylolm' function from the phylolm package (Ho & Ane, 2014). In order to assess the model fit and relative effect sizes of explanatory variables in the phylogenetically constrained models we **XXXXXXXXXXXXXXXXXXXX**.

All models and analyses were conducted in the R computing environment (R Core Team, 2017) and relied heavily on the tidyverse environment (Wickham, 2017).

RESULTS

A total of 637,482 checklists provided a total of 5,944,819 observations of 580 different species which had > 100 observations. The least recorded species was Black-breasted Buttonquail (N=104) while the most recorded species was Australian Magpie (N=158,615). The mean \pm SD number of observations for a species was $10,250 \pm 19,269.19$.

We ended with 569 candidate species (Appendix 3) from the eBird dataset which matched both the trait taxonomy and the phylogenetic tree taxonomy, and also had complete trait data.

Urbanization index

For the 569 species included in the models the mean \pm SD urbanization index was 1.11 ± 2.17 , with a range from 0.001 (Black Noddy and Black-naped Tern) to 20.15 (Laughing Dove; Fig. 2).

Phylogenetic signal

There was a distinct phylogenetic signal in our urbanization index measure (Fig. 3; XXXXX SIGNIFICANCE TEST).

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Model results

Non phylogenetic models

Phylogenetically constrained models

DISCUSSION

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Figures

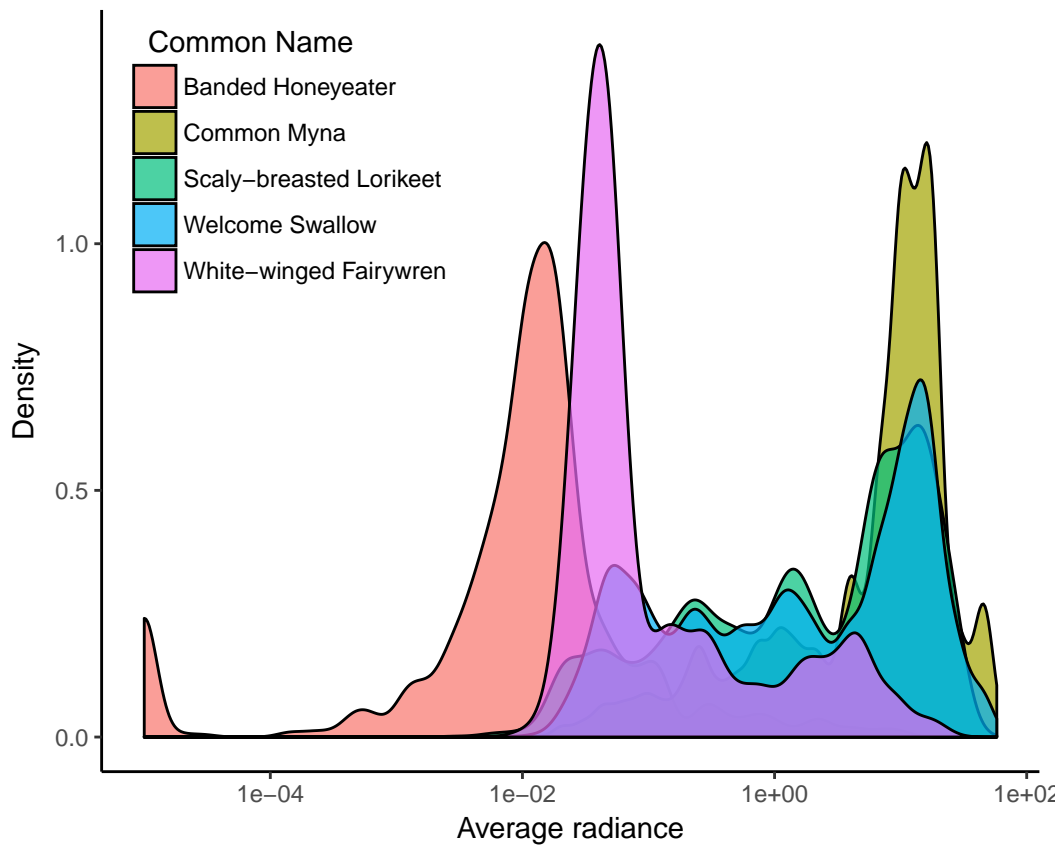


Figure 1: An example of five different species' average radiance values

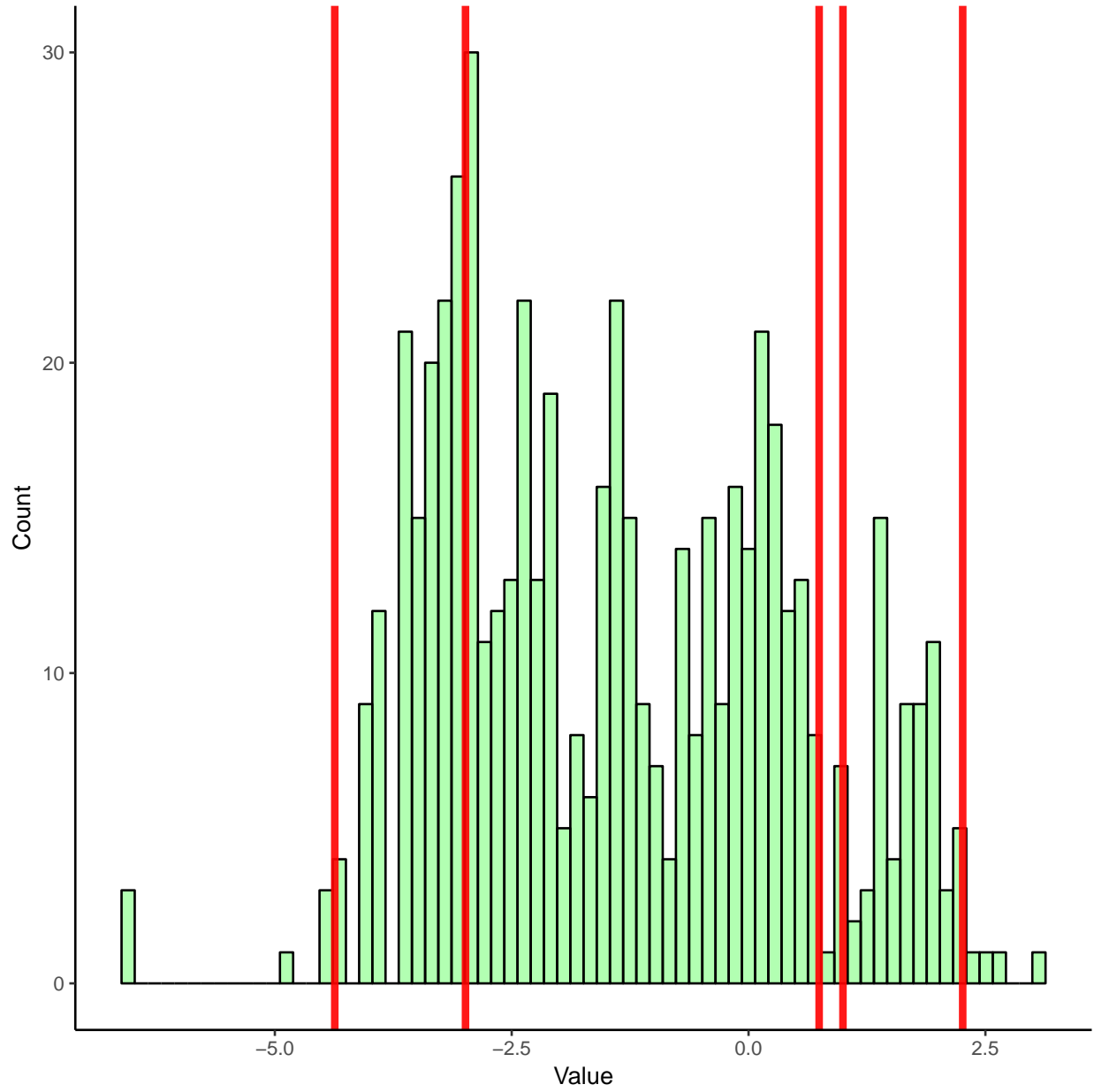
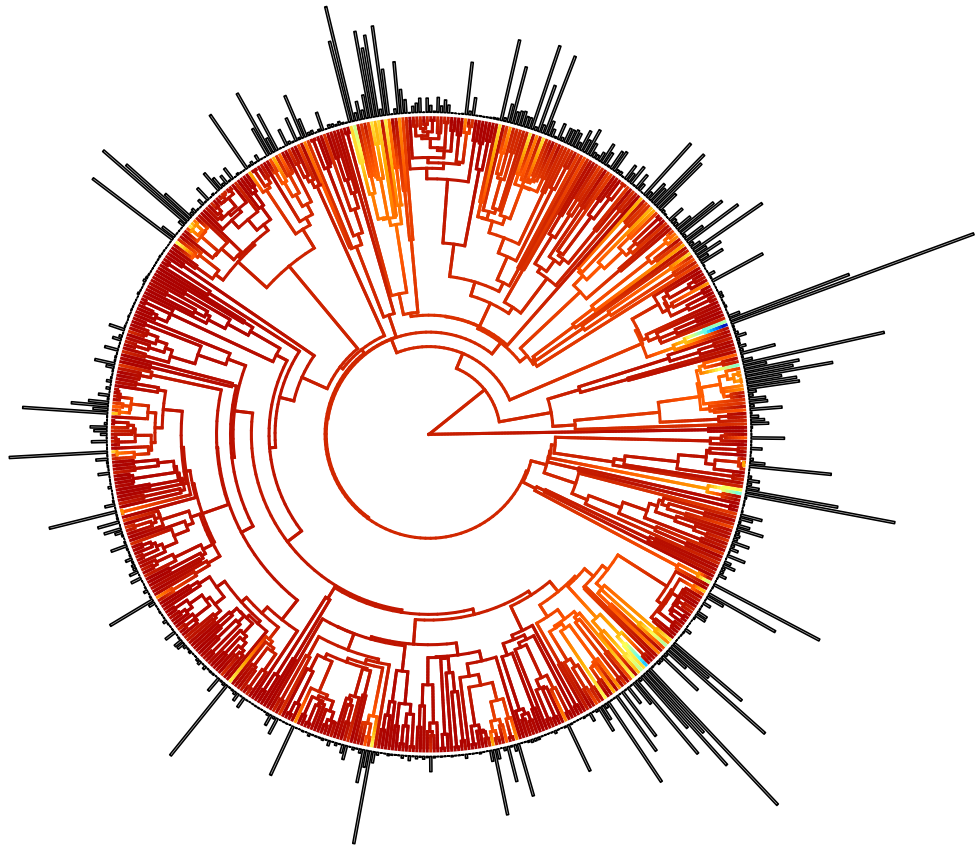


Figure 2: The distribution, on a log-scale, of the response variable for the 569 species included in the analysis, with five example species highlighted.



0 trait value 20.1
length=100

Figure 3: A phylogenetic tree of the birds yata yata yata. . . .