The Greenspace Bird Calculator: a citizen-driven tool for monitoring avian biodiversity in urban greenspaces

Corey T. Callaghan[1,*], John H. Wilshire[1], John M. Martin[1], Richard E. Major[1,2], Mitchell B. Lyons[1], Richard T. Kingsford[1]

[1]Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, UNSW Sydney, Sydney NSW 2052

[2]Australian Museum Research Institute, Australian Museum, 1 William Street, Sydney NSW 2010

*Corresponding author: c.callaghan@unsw.edu.au

ABSTRACT

Urbanisation is altering local flora and fauna, but urban greenspaces can provide refugia for a variety of taxa. However, we often lack basic biodiversity information (e.g., species richness) for these urban greenspaces. Citizen science projects are continuously improving our understanding of ecology at broad temporal and spatial scales. But, many conservation-relevant decisions are idiosyncratic and made at small management scales (e.g., local government). Given a general bias of citizen science data towards areas with large human populations, citizen scientists are best placed to contribute to improving our understanding of the biodiversity within cities and urban greenspaces. We introduce the Greenspace Bird Calculator: a web-app aimed at enhancing our collective knowledge of bird diversity in urban greenspaces. Users of the web-app could be land managers seeking to understand the bird diversity in the greenspaces they manage. It is built in a reproducible workflow, allowing anyone to delineate a greenspace and submit it to the web-app administrator, receiving an output comprising the greenspace's total bird diversity. The Greenspace Bird Calculator web-app provides an automated tool to utilise existing eBird citizen science data to calculate species richness for urban greenspaces globally. Critically, the GBC web-app statistically assesses available data that otherwise would be unlikely to be considered by decision-makers. This web-app is an example of the evolution of citizen science, whereby the data collected has been analysed to allow accessible interpretation and inclusion into urban greenspace management and planning.

Key words: citizen science; eBird; species richness; urban ecology; bird surveys

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Introduction

Urban sprawl and development are projected to increase globally (Jiang et al. 2017), resulting from human population growth and associated agricultural concentration (Chen 2007). Habitat fragmentation and degradation, resulting from urban sprawl and development, negatively impacts local flora and fauna, leading to localised extirpations (McKinney 2006, 2008). Despite this, urban greenspaces (e.g., parks, sports fields, remnant bush, cemeteries, golf courses) can support relatively high biodiversity compared with natural or rural habitats (Madre *et al.* 2014), and may even support threatened species (Ives et al. 2016). Due to increasing urbanization and diverse stakeholder views, urban greenspaces are ongoing targets for potential development. Conserving urban biodiversity (Dearborn and Kark 2010) benefits people, providing ecosystem services (Luederitz *et al.* 2015) and improving physical and mental health (Fuller *et al*. 2007, Carrus *et al*. 2015). Indeed, there is broad public support for biodiversity within cities (Fischer *et al.* 2018). Support for urban greenspaces and their associated biodiversity requires improved understanding and appreciation of their values.

Citizen scientists can contribute to improving our understanding of the biodiversity within cities and urban greenspaces (McCaffrey 2005). Citizen science is an increasingly popular activity, with hundreds of thousands of individuals involved in diverse projects, with significant ecological and conservation benefits (Silvertown 2009, Dickinson *et al*. 2010). Limitations to citizen science data often include spatial and temporal bias (Boakes et al. 2010), and disproportionate collection near areas of high human populations (Kelling *et al.* 2015), potentially limiting the questions that can be answered using these data. Yet, for ecological questions within urban areas, biases which exist in citizen science data can, in some cases, be considered advantageous. Citizen science data offers great potential to answer questions within urban areas (McCaffery 2005, Cooper *et al.* 2007), and of all taxa, birds probably benefit from citizen science the most. There is a long history of citizens contributing to ornithology, and many of the early ornithologists and ecologists could be considered 'citizen scientists'. Bird-focused citizen-science projects date back to the early 20th century, e.g., Christmas Bird Counts (National Audubon

Society 2012). Other popular long-standing projects include the Australian Bird Atlas (~1977; Blakers *et al.* 1984, Barrett et al. 2003), and the North American (~1966; Sauer *et al.* 2014) and British (~ 1992; Risely *et al.* 2009) breeding bird surveys.

Extending citizen science data to decision makers

Citizen science projects are diverse, ranging from unstructured to structured (Welvaert and Caley 2016; Callaghan *et al.* 2018a), and from local-scale to global-scale, often with poor integration among projects (Jackson *et al. this issue*). Many global-scale projects are focused on broad implications, and these large-scale projects have furthered our understanding of ecology broadly (e.g., Hochachka *et al.* 2012, Andrew *et al.* 2017). However, many conservation-relevant decisions are idiosyncratic and made at small management scales (e.g., local government). Further, land managers are frequently unaware of what data are available to help make decisions. This is particularly true in urban areas, where research funding can be difficult to attain. Often, the simplest of questions are difficult to answer, but simple questions regarding metrics such as species richness are fundamental for land management and crucial for conservation and management of biodiversity (Boulinier *et al.* 1998). For instance, how many bird species have been seen in a specific urban greenspace? Or, how many bird species regularly use an urban greenspace? If, when faced with potential development, this basic information is lacking, it is exceedingly difficult to support a case against development of urban greenspaces. However, these data need to be scientifically defensible and easily available to potential end-users (e.g., decision makers, local governments, and naturalist groups).

Our objective was to develop an iterative tool, relying on citizen scientists, that analyses data and presents it in a fashion which is easily understandable. We further aimed to develop an updateable tool that greenspace managers can use to include their greenspace for analyses. In this paper, we introduce the Greenspace Bird Calculator (hereafter: GBC), a web-app aimed at enhancing our collective knowledge of bird diversity in urban greenspaces. Users of the web-app could be land managers seeking to understand the bird diversity in the greenspaces they manage or restoration groups aimed at tracking responses to restoration through time. It is built in a reproducible workflow, allowing anyone to delineate a greenspace and submit it to the web-app administrator, receiving an output comprising the greenspace's total bird diversity. This functionality allows for broad use of citizen science projects, and infrastructure for 'grass-roots' efforts, assisting those who may be interested in better understanding their local bird community.

The Greenspace Bird Calculator (GBC) web-app

The web-app builds upon previously published research demonstrating the validity of eBird citizen science data in urban greenspaces (Callaghan *et al.* 2017, 2018a, 2018b), but focuses on providing data in an easy-to-access format. The GBC web-app relies on two key components (Figure 1): (1) delineated urban greenspaces and (2) eBird data (Sullivan *et al.* 2009, 2014), generated through a global citizen science project which has been shown to have local-scale relevance (Callaghan *et al.* 2015, Sullivan *et al.* 2017). eBird does provide summary information for some urban greenspaces which are delineated as 'hotspots' (e.g., https://ebird.org/australia/hotspot/L3033858), but this is generally geared towards allowing birders to be aware of the latest information at a greenspace. Our approach differs in that we focus on filtering the data first (Callaghan *et al.* 2017) and analyzing the data from an urban greenspace and presenting it in an easy-to-use format. We also have designed the GBC web-app with the ability to add any potential urban greenspace, not reliant only on 'hotspots' in eBird.

Urban greenspaces

Most studies fail to define urban greenspace, providing a wide range of definitions (Taylor and Hochuli 2017), reflecting different stakeholders with interests in urban greenspaces. Indeed, urban greenspaces are not easily defined, given different types of green infrastructure within cities. It can be loosely defined as any area which comprises vegetation, associated with natural elements (Taylor and Hochuli 2017). Our definition correlates to the end-goal of our research project: understanding the bird community in a manageable unit. As such, we define an urban greenspace by the following characteristics: (1) it is surrounded by 'built-up' landcover on at least three sides, as judged by aerial imagery, (2) it is easily delineated from what can be considered remnant vegetation (e.g., natural bushlands adjacent to the city), and (3) it is qualitatively different from any adjoining greenspace (e.g., a cemetery adjoining a park would be considered two separate greenspaces). This definition has some subjectivity (Figure 2), but we highlight that those with local knowledge of the manageable unit in a given city would better be able to delineate greenspaces of interest; a key component of our reproducible workflow (see below). For example, Sydney Park and Kensington Oval are completely surrounded by built-up areas and are thus easily termed urban greenspaces. Contrasting this, are the golf courses of the eastern suburbs of Sydney which make one large greenspace unit, but with different management regimes only known from local knowledge (Figure 2).

Delineating an urban greenspace

Given that the GBC web-app is powered by existing eBird data, the main data which needs to be 'collected' for the site-specific calculations to work are individually

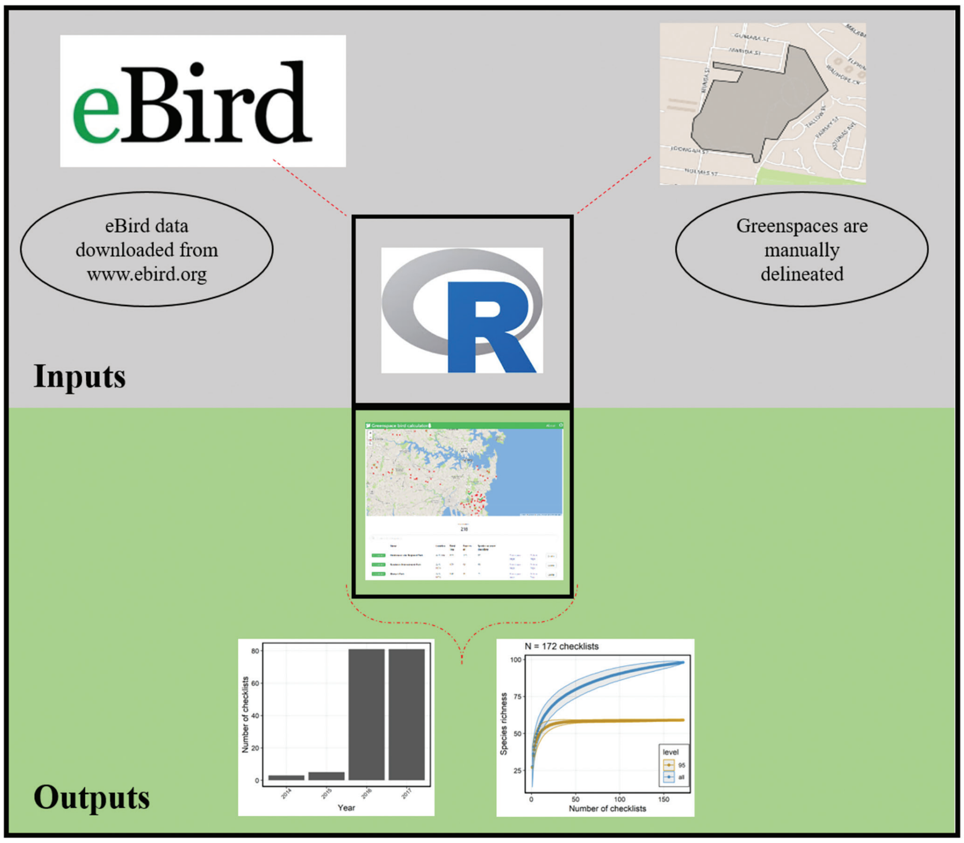

Figure 1. The structure and workflow of the Greenspace Bird Calculator (GBC) web-app. eBird data and delineated urban greenspaces (inputs: in grey) are aggregated and analyzed using R statistical software, and summary files (outputs: in green) are produced for each urban greenspace, accessible through the GBC interface.

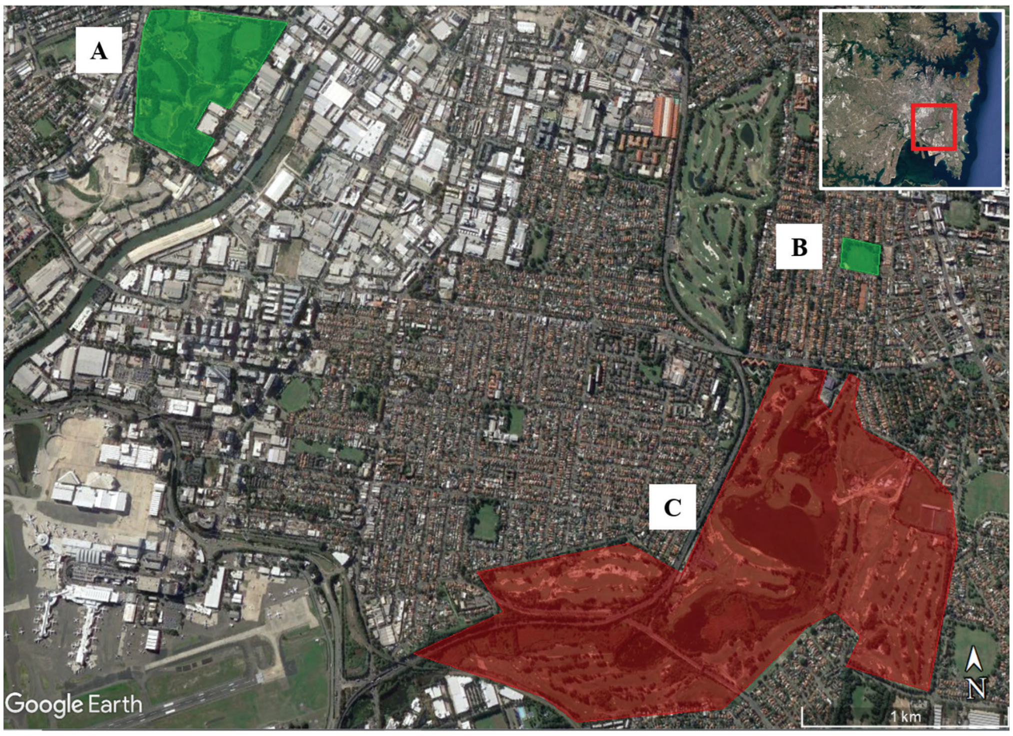

Figure 2. Example delineating a greenspace: Sydney Park (**A**) and Kensington Oval (**B**) are easily delineated as they are completely surrounded by built-up areas, whereas (**C**), comprised of Bonnie Doon Golf club, Eastlake Golf Club, and The Lakes Golf Club would be difficult to separate without local-knowledge of the different golf courses.

delineated urban greenspaces (Figure 2). This is done using an online tool to delineate a polygon in GeoJSON format. This file format (*.geojson*) is an open standard designed for representing simple geographical features, based on JSON language (https://en.wikipedia.org/wiki/GeoJSON). We used geojson.io website, but other options are available to delineate a greenspace. The delineated greenspace file is then submitted to the GitHub repository (*see Technical details below*) and the eBird data associated with the location will be calculated on a quarterly basis.

eBird citizen science data

eBird, launched in 2002, is a citizen science project run by the Cornell Lab of Ornithology (Sullivan *et al.* 2009, 2014), with > 600 million observations contributed by > 400 thousand observers, and > 180 peer-reviewed publications. It is a semi-structured project, whereby observers report 'checklists' of birds seen and/or heard while birdwatching, as well as counts of each species. Based on the spatiotemporal coordinates of the observation, a checklist with the most likely birds to occur is pre-generated. When a species or count of species is seen outside these pre-set filters, then that record is reviewed by regional experts before acceptance. These data have progressed understanding of ecology at a broad-scale (e.g., Fink *et al.* 2010, Johnston *et al.* 2015), but also provide comparable biodiversity estimates at a small-scale (Callaghan *et al.* 2015, 2018a). eBird data are updated monthly and publicly accessible to researchers and practitioners (https://ebird.org/data/download).

Assessing species richness in an urban greenspace using eBird data

Species richness is a simple, intuitive, and straightforward means of measuring biodiversity, easily translated to non-specialist audiences. For example, it is easy to understand differences between two greenspaces of 30 and 100 species, respectively, and most decision makers would place more value on the more diverse greenspace.

Determining exactly how many species are in a given spatial area is not easy. Substantial research has been devoted to species accumulation curves (Thompson and Withers 2003, Ugland *et al.* 2003), aimed at estimating the number of species at a given location. From the perspective of sampling urban greenspaces using eBird data, unconstrained spatial coverage from eBird data leads to increased estimates of species richness, compared with more structured sampling protocols (Callaghan *et al.* 2018a). However, opportunistic data collection is associated with biases. For example, observer skill, time spent birding, distance travelled, time-of-day, weather conditions, and time-of-year all influence the number and composition of species seen. Given the unconstrained data collection of eBird, biases may exist on any given eBird checklist, but they can be accounted for by employing a bootstrapping framework to estimate species richness within an urban greenspace. This approach works by calculating species richness for each of {1, 2, 3, …, n} checklists at a greenspace, using a random subsample with replacement of the checklists each time. Thereby, any given checklist is allowed the same probability of being 'chosen', despite its biases. Before employing this approach, checklists downloaded from eBird are first subsampled to include the 'best quality' lists (see Callaghan *et al.* 2017 for details). Another form of bias is birders' aptitude for maximising the list of species seen in a given spatial extent (i.e., exhaustive survey), with their dedication to finding vagrants (Booth *et al.* 2011, Callaghan *et al.* 2018c), incrementally increasing their list for a given site. From a management perspective, the vagrants (i.e., one-off individual birds) are not a 'core' part of the avifauna of a local urban greenspace. Indeed, previous work has shown that if species which are found on fewer than 5% of eBird checklists within a site are removed from analyses, only 17 checklists (i.e., 17 bird surveys) on average are necessary to estimate 90% of the species richness in a greenspace (Callaghan *et al.* 2017).

Our methodological approach treats each checklist as an independent survey, accounting for the variation which exists among checklists within an urban greenspace. However, there are also differences which exist among greenspaces that could influence how many checklists would be necessary to fully sample the bird community. The diversity of habitats, the size of the regional species' pool, the size of the greenspace, and the accessibility of the greenspace all influence how many checklists would be necessary to sample the avian community. These inter-greenspace differences highlight the necessity of a flexible workflow that is generalisable among greenspaces.

Technical details

The GBC relies on two inputs: (1) eBird basic dataset (https://ebird.org/science/download-ebird-data-products), updated quarterly from the Cornell lab of Ornithology (Figure 1), and (2) a dataset of delineated urban greenspaces. The eBird dataset is stored in a spatially indexed MariaDB database, accessed using the dbplyr package in R (Wickham and Ruiz 2018). The dataset of urban greenspaces is stored as separate files in a GitHub repository, in GeoJSON (*.geojson*) format.

GBC is an open-source web-app written in JavaScript using the Vue framework and is reliant on Github for hosting and programmatic access to the GitHub repository for accessing pre-generated figures and species lists. This allows the figures to be separately downloaded as well, from the GitHub repository. The bird data are then joined with our dataset of urban greenspaces. Then, for each greenspace, all eBird checklists are aggregated and filtered. We then analyse the confidence in the number of eBird surveys for each greenspace, plotted and made available in the front-end of the GBC web-app. The GBC provides a list and visual exploration of

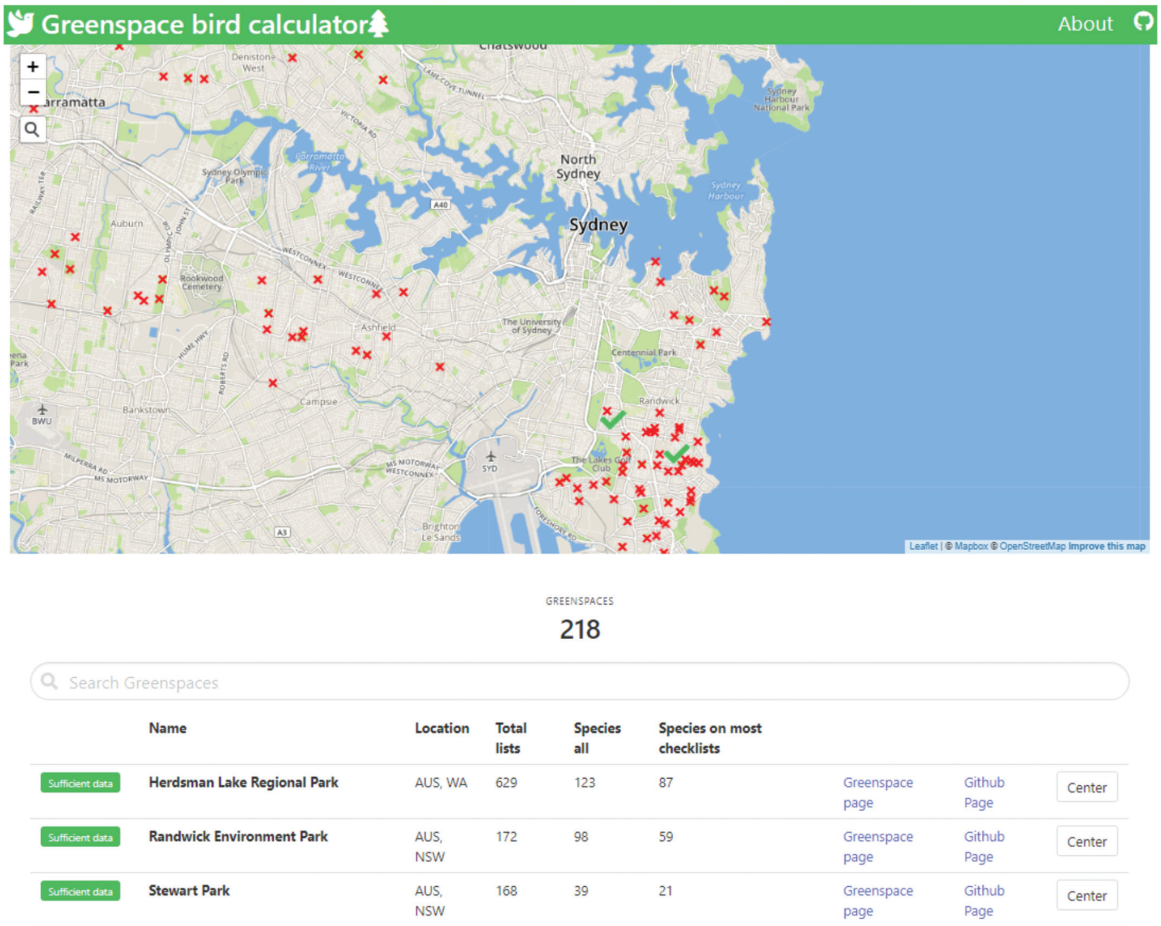

Figure 3. The web-interface of the GBC. Users can search for an urban greenspace by either choosing one from the map or using the search bar. Only urban greenspaces with > 40 eBird checklists are currently analyzed and presented, represented by a green checkmark (delineated greenspaces which do not have > 40 checklists are represented by a red x). Clicking on the "Greenspace page" takes the user to the relevant plots (Figure 4), while clicking on the "Github page" takes the user to downloadable raw files. This webpage can be found at: https://coreytcallaghan.github.io/urban_greenspaces/#/.

all delineated urban greenspaces. A user can then find a greenspace and explore the results of the analyses, if their greenspace has sufficient data for analysis. We consider a greenspace to have sufficient data for analysis if it has a minimum of 40 eBird checklists.

An example greenspace

An individual urban greenspace is chosen from already delineated greenspaces, using the GBC interface (Figure 3). If a given greenspace does not exist, then the user can submit a delineated greenspace file, as discussed above. We chose Kensington Oval – a small urban greenspace located in Kensington, New South Wales. Once the greenspace was chosen, the user was presented with a web-page with the following information (Figure 4): (1) the total number of species reported (including all species' observations and the total number of species once those species which occur on < 5% of eBird checklists are removed), and a figure showing the species accumulation curve; (2) the number of checklists reported through time, annually; and (3) a list of the species reported for a given site, ranked by reporting rate. Reporting rate was defined as the percentage of eBird checklists on which a given species occurred. In addition, there was an inset map of the greenspace, and background information on the web-app.

Discussion

We present a tool designed for better understanding the bird community in local urban greenspaces, and providing the data to end-users in an easily accessible format. This tool will be useful in decision-making, aiding our understanding of prioritisation against development of urban greenspace, and for urban planning of future urban greenspaces. This is the first release of the GBC web-app, which will continue to increase in quality and quantity of underlying data and greenspaces represented, and we will continue to build in other measures of species' change necessary for urban greenspace managers (see "future directions" below). We will continue to work with end-users to refine both data requirements and the web-app implementation. Potential areas for improvement in next iterations of

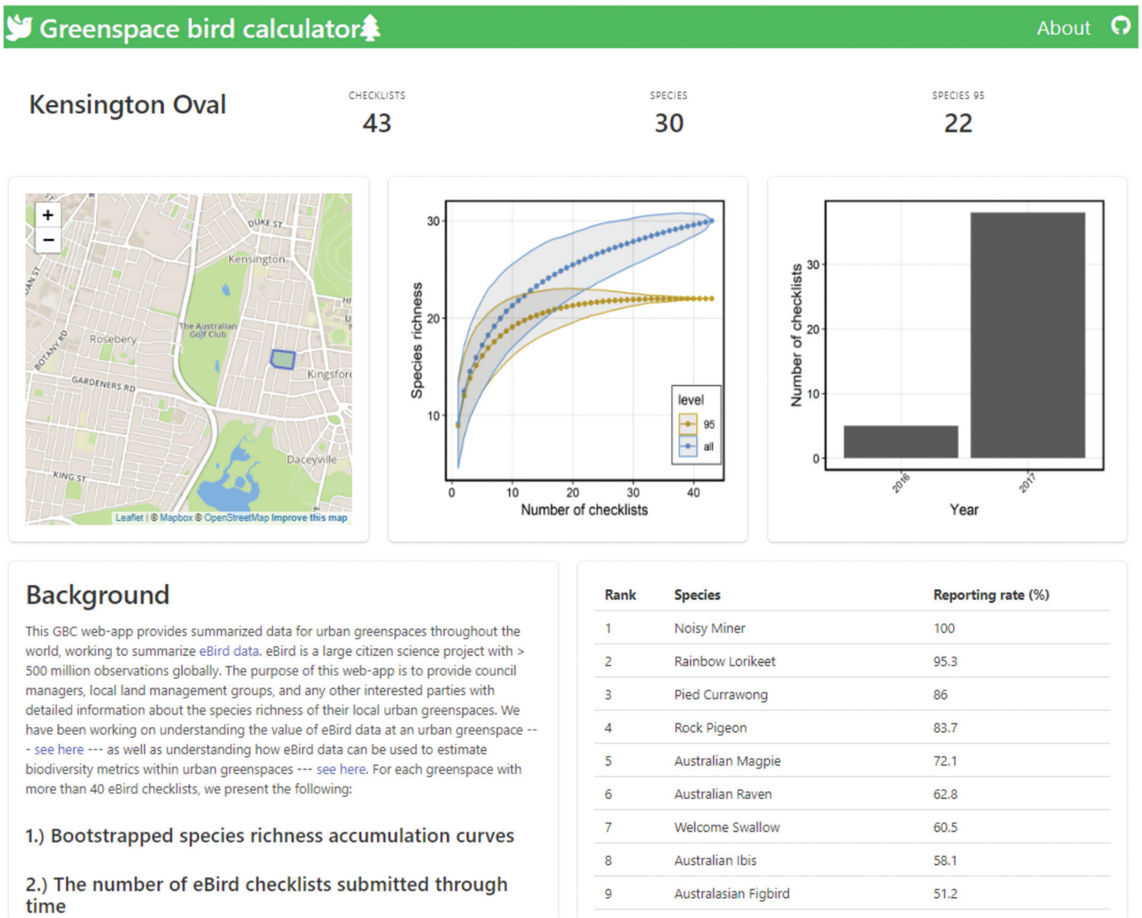

Figure 4. The summarized outputs for Kensington Oval, Kensington, New South Wales. The data presented are: (1) the total number of species reported (including all species' observations and the total number of species once those species which occur on < 5% of eBird checklists are removed), and a figure showing the species accumulation curve; (2) the number of checklists reported through time; and (3) a list of the species reported for a given site, ranked by reporting rate.

the app include user friendliness, display of data, and additional methods with which the data analysis can be downloaded. Further, interested users will be able to report bugs and provide suggestions by interacting on the GitHub repository's 'issues' page: https://github.com/coreytcallaghan/urban_greenspaces/issues.

Not all urban greenspaces are created equal

Urban greenspaces are inherently different in purpose and bird communities (cf., a sports oval vs. urban wetland). The data in eBird comes from birders, generally trying to see as many bird species as possible, and as such there are likely to be biases whereby birders disproportionately visit the most 'popular sites', known for birding (e.g., Callaghan *et al.* 2018b). Small greenspaces may not have much data and thus cannot be assessed for their bird community until additional eBird surveys are conducted. However, the GBC web-app provides the infrastructure which would allow analysis once the threshold is met, allowing for robust and standardized comparisons, both spatially and temporally. Knowing that this tool is available, greenspace managers could encourage local naturalists to contribute data through the eBird portal so that the minimum data threshold is achieved. For some areas, a lack of awareness of an efficient platform for collection (eBird) and analysis (our GBC web-app) of survey data may be inhibiting people from contributing data.

Future directions

In the first iteration of the GBC we disregard inter and intra-annual changes in species richness. In highly migratory systems (e.g., northern hemisphere) there are distinct seasonal differences in urban greenspace usage by birds (La Sorte *et al.* 2014). In Australia, these differences are relatively minor for terrestrial species (i.e., excluding shorebirds). However, we will continue to develop the web-app, allowing end-users to investigate temporal differences if interested, but this relies on sufficient eBird data from all seasons to investigate with confidence. eBird data are relatively new to Australia, and thus many sites are lacking long-term datasets, limiting our ability to track species richness through time. However, given the current uptake of the eBird project in Australia, and globally (Wood *et al.* 2011), we anticipate that inter and intra-annual changes in species richness will be feasible in the near future.

Species richness is an essential component of biodiversity, necessary for fully understanding what species live in a particular area. This is important in a conservation framework of urban greenspaces (Boulinier *et al*. 1998, Lepczyk *et al*. 2017), allowing managers to understand which greenspaces have the highest level of bird biodiversity for mitigation and conservation. However, there are a number of shortcomings associated with species richness (Gotelli and Colwell 2001), including the difficulty of extrapolating to useful landscape metrics necessary for greenspace management (e.g., accounting for the size of the regional species pool). Accordingly, in our current web-app and presentation of data, comparisons of greenspaces within a city focused on species richness are likely to be valid, but comparisons among cities would need to be scaled by the regional species pool. This is an area of focus to improve in the next iterations of the GBC web-app. Indeed, measuring the species-specific responses to urbanization, on a continuous scale is important to understand how the species which comprise an avian community compares among greenspaces (Callaghan *et al*. 2019), and we intend to implement this approach to future versions of the web-app.

Conclusion

The GBC web-app provides an automated tool to utilise existing eBird citizen science data to calculate species richness for urban greenspaces globally. Critically, the GBC web-app statistically assesses available data that otherwise would be unlikely to be considered by decision-makers. This web-app is an example of the evolution of citizen science, whereby the data collected are analysed to allow accessible interpretation and inclusion into urban greenspace management and planning.

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