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Avian monitoring – comparing structured and unstructured citizen science

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Abstract

Context. Citizen science is increasingly used to collect biodiversity data to inform conservation management, but its validity within urban greenspaces remains largely unresolved.

Aims. To assess the validity of eBird data for generating biodiversity estimates within an urban greenspace.

Methods. We compared data from structured avian surveys with eBird data at an urban greenspace in Sydney during 2012–16, using species richness and Shannon diversity indices. We also compared community composition, using non-metric multidimensional scaling (NMDS) and dissimilarities using non-parametric MANOVA.

Key results. Structured surveys had a lower overall species richness (80 versus 116) and Shannon diversity (3.64 versus 3.94) than eBird data, but we found no significant differences when using years as replicates. After standardising the richness and diversity indices by time spent surveying in a given year, structured surveys produced significantly higher biodiversity estimates. Further, when grouped into species occupying different broad habitats, there were no significant differences in waterbird or landbird species richness, or in Shannon diversity between data sources.

Conclusions. The most likely explanation for the larger magnitudes of the biodiversity indices from the eBird data is the increase in effort manifested in the number of observers, time spent surveying and spatial coverage. This resulted in increased detection of uncommon species, which in turn accounted for a significant difference ($R^2 = 0.21$, $P = 0.015$) in overall community composition measured by the two methods.

Implications. Our results highlight the opportunities provided by eBird data as a useful tool for land managers for monitoring avian communities in urban areas.

Additional keywords: atlas, bird surveys, community composition, eBird, Shannon diversity, species richness, urban ecology, urban greenspace.

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Introduction

Citizen science projects vary in scope, scale and study system (Bonney *et al*. 2009; Miller-Rushing *et al*. 2012; MacKenzie *et al*. 2017), and have the potential to build and sustain conservation activities across multiple scales (e.g. Wiersma 2010; Ellwood *et al*. 2017). In addition to the benefits of data collection, citizen science also engages and stimulates participants (e.g. Domroese and Johnson 2017; Ellwood *et al*. 2017). Citizen science projects can be divided into structured (i.e. intentional reporting and standardised survey periods, often with trained and experienced observers) and unstructured (i.e. intentional reporting and unstandardised survey periods, often with no formal training required for participants and generally incidental in nature) designs (Welvaert and Caley 2016). However, citizen science data are often questioned on the grounds of data quality and integrity (Cohn 2008; Dickinson *et al*. 2010; Bird *et al*. 2014). In particular, unstructured projects can produce spatially and temporally biased data (Boakes *et al*. 2010), due to a disproportionate number of sightings along roadways or in urban areas with high human population density (Kelling *et al*. 2015*a*), and a propensity for surveys to be undertaken on weekends (Courter *et al*. 2013). However, statistical solutions, such as mixed-effects models accounting for pseudo-replication, or modelling the sampling process with hierarchical frameworks (Bird *et al*. 2014), can help account for biases (e.g. Fink *et al*. 2010; Welvaert and Caley 2016), especially when the 'noise' is identified (Isaac *et al*. 2014). Concomitantly, there is also increasing evidence, across disciplines, that citizen science and expert-collected data show strong agreement (e.g. Hoyer *et al*. 2012; Gollan *et al*. 2012; Vianna *et al*. 2014).

For example, mark–recapture models for whale sharks were equally reliable whether using sightings reported by the public or by experienced researchers (Davies *et al*. 2012), and volunteers performed almost as well as professionals in identifying and monitoring invasive plant species (Crall *et al*. 2011). Citizen science data are increasingly sourced and used by the scientific community, as evidenced by a substantial increase in publications related to citizen science (Jordan *et al*. 2015; Welvaert and Caley 2016). However, studies that address the validity of citizen science data across multiple spatial and temporal scales are still necessary to provide confidence in results stemming from citizen science projects.

Citizen science focusing on birds is well established through projects such as the Christmas Bird Counts (National Audubon Society 2012), the British (Risely *et al*. 2009) and North American (Sauer *et al*. 2014) Breeding Bird Surveys, the Atlas of Australian Birds (Blakers *et al*. 1984; Barrett *et al*. 2003) and eBird (Sullivan *et al*. 2009, 2014). Augmenting structured surveys with such citizen science data can improve spatial and temporal scales of conservation monitoring (Wood *et al*. 2011; Lowe *et al*. 2011; Tulloch *et al*. 2013), perhaps importantly in urban ecosystems, which are usually not a priority for such funding (Kobori and Primack 2003; Evans *et al*. 2005; Kobori *et al*. 2016).

Despite the long-standing tradition of citizen science in bird monitoring, investigators have only recently begun to validate certain aspects of citizen-based bird data (e.g. Nagy *et al*. 2012; Jackson *et al*. 2015; Miller *et al*. 2016). In particular, comparisons between structured and unstructured citizen-based bird data have revealed mixed results. For instance, volunteer-collected data were weakly positively related to a national bird monitoring scheme in Sweden, but the relationship also varied (positively or negatively) among species groups (Snäll *et al*. 2011). Unstructured surveys failed to detect long-term population declines of common birds in Denmark (Kamp *et al*. 2016), but there was little difference in relative population estimates between structured and unstructured monitoring in Australia (Szabo *et al*. 2012). Moreover, unstructured eBird data have been shown to provide a similar information content to that of structured Breeding Bird Surveys (Munson *et al*. 2010). However, such coarse spatial scale comparisons are seldom replicated at fine spatial scales (but see Callaghan and Gawlik 2015).

eBird is a citizen science project (Sullivan *et al*. 2014) with more than 500 million observations reported since its launch in 2002. It capitalises on the behaviour of bird enthusiasts worldwide (Wood *et al*. 2011), following an unstructured approach, with no formal training required to submit sightings. However, most data come from ‘power users’ (Wood *et al*. 2011) who can often be considered ‘amateur experts’. Regional reviewers validate sightings, based on filters of expected bird species and counts, created by a sighting’s spatiotemporal coordinates (Wood *et al*. 2011). eBird data at the Cornell Lab of Ornithology are freely accessible to researchers, providing an increasingly powerful source of data. Bird assemblage data, recorded through eBird, are increasingly analysed (>135 publications), but generally address broad-scale questions (e.g. Hochachka and Fink 2012; Hochachka *et al*. 2012; La Sorte *et al*. 2013, 2016). Analyses of the fine spatial scale applicability of eBird data, including effectiveness in sampling entire bird communities (Callaghan *et al*. 2017), are also important, given that management decisions are typically made at fine spatial scales (Semple and Weins 1989). Determining if eBird data favour particular species or taxa of birds is also important (e.g. Snäll *et al*. 2011).

Our objective was to measure the performance of unstructured eBird data in assessing the avifaunal community of an urban greenspace in Sydney, Australia. To do this, we compared eBird data with data obtained from structured surveys specifically designed to monitor the park’s avifauna. Both data sources collected information on the number of birds of each species encountered during a discrete survey. To investigate bias in reporting different types of birds, we divided the bird community into landbirds and waterbirds before testing for differences between the two datasets in species richness and Shannon diversity. Specifically, we predicted that landbirds, which are generally smaller and more difficult to find, would have more observations through the unstructured protocol than the structured protocol, as a result of increased survey effort (temporal and spatial coverage).

Methods

Study area

Our study was conducted in Centennial Park (33° 53′ 53.88″ S, 151° 14′ 3.12″ E), a large greenspace (189 ha) in central Sydney, Australia, surrounded by residential dwellings and commercial facilities. The park has a range of habitats with native and exotic vegetation, including woodland areas, native heath and dunes, modified ponds with islands and wetlands, and open sport fields. An estimated 20 million people visit the park each year (Centennial Parklands 2015).

Data sources

Bird surveys were conducted by members of the Birding New South Wales (NSW) club (hereafter referred to as NSW surveys). These surveys were standardised area-search surveys lasting 15 min, adapted from the Atlas of Australian Birds 20 min method (Barrett *et al*. 2003). All birds identified both visually and audibly within 2 ha of a given point were recorded, as was each species’ abundance estimate. There were 15 predetermined locations throughout Centennial Park, generally visited fortnightly, in either the morning or afternoon. Surveys were collected in paper format. In total, 11 different observers, all of whom were experienced birdwatchers with cumulative decades of experience with Sydney’s birds, conducted 242 different area-search surveys in teams of one to three at the 15 predetermined points between June 2012 and June 2016.

We compared these data with eBird data collected over the same period and submitted by volunteers who recorded the location, date, time of day and duration of their bird-watching. eBirders generally use a mobile phone app to record their observations and can record either abundance estimates or solely presence of species seen and/or heard. There are no restrictions to eBird surveys’ length, frequency or distance travelled; eBirders are free to survey at any time of day with any temporal frequency, but they must indicate whether each list is a complete list of birds seen and/or heard (see Wood *et al*. 2011; Sullivan *et al*. 2014 for further details about eBird methods).

Contrary to the NSW surveys, which were not vetted or filtered because they relied on a small team of experienced birdwatchers collecting the data, eBird data are automatically filtered as part of the collection protocol based on expected bird species, their abundance and the spatiotemporal coordinates of the sighting. These automatic filters are more critical because eBird relies on observers with a wide range of skills, ranging from beginner to expert (Kelling *et al*. 2015*b*). Reported observations of unexpected species are reviewed by local experts before they are added, or not, to the database. We downloaded the eBird Basic Dataset (version ebd_AU-relAug-2016; data can be downloaded at https://ebird.org/data/download), and restricted the dataset to complete checklists where observers followed a travelling or exhaustive protocol. Observations without abundance estimates (i.e. simple presence or absence data only) were excluded from our analysis of eBird data, resulting in a dataset of 178 surveys contributed by 74 observers.

Analysis

We used two commonly employed metrics of biological diversity (Magurran 2004; Morris *et al*. 2014), species richness (S) and Shannon diversity (H′), as well as the Bray–Curtis similarity (Bray and Curtis 1957) as a measure of community composition, for our comparisons. Species richness is the total number of species in a community and Shannon diversity is another measure of community diversity that accounts for species richness and the proportion of each species in a community (Magurran 2004). Overall species richness and Shannon diversity were calculated by pooling data from all 5 years for each data source. A robust *t*-test (Hutcheson 1970; Zar 1999) was used to test for a possible difference in Shannon diversity between the two data sources. We also calculated species richness and Shannon diversity for each year (2012–16). Mean counts of each species were calculated per year to estimate Shannon diversity. We also repeated these analyses, but accounted for the different survey effort between data sources by dividing species richness and Shannon diversity by the total number of minutes spent surveying during each year. Subsequently, we calculated species richness and Shannon diversity separately for both waterbirds and landbirds. We used *t*-tests to investigate differences between data sources, using year as a replicate. For samples with equal or unequal variances, we used the student's two-sample *t*-test (Zar 1999) and Welch's two-sample *t*-test, respectively (Ruxton 2006).

Lastly, we used non-metric multidimensional scaling (NMDS) with Bray–Curtis similarity of a presence/absence matrix to visualise differences in community composition between data sources. A non-parametric MANOVA (Anderson 2001) was used to identify significant differences in community composition due to year and data source, and a similarity percentages procedure (SIMPER) was used to investigate the species that explained differences in community composition, using the vegan package (Oksanen *et al*. 2016). Significance was determined at $\alpha = 0.05$, and all analyses were completed in R statistical software (R Core Team 2016).

Results

The number of species recorded during the NSW surveys ($n = 80$) was 30% lower than the number recorded through eBird surveys ($n = 116$; see Table S1 for species names). This difference in species richness was reflected in the overall Shannon diversity, calculated by pooling data from all 5 years, which was significantly lower for the NSW surveys (3.64) than the eBird data (3.94; $t_{751.7} = -4.0$, $P < 0.0001$). Using years as replicates, Shannon diversity ($t_{5.3} = -2.7$, $P = 0.04$) was significantly higher for the eBird data than the NSW survey data, and the difference in species richness was also correlative ($t_{5.6} = -2.2$, $P = 0.07$).

The number of contributions to the eBird database and time spent surveying increased during the study period (Table 1). There were also temporal changes in diversity determined from eBird data, with species richness increasing over time. In contrast, species richness based on the NSW surveys remained relatively constant (Fig. 1*a*). However, Shannon diversity remained relatively constant for both data sources over the study period (Fig. 1*b*). To investigate these trends further, we accounted for survey effort by dividing by time spent surveying and, after this adjustment, NSW surveys had significantly higher standardised richness ($t_{8.0} = 3.4$, $P = 0.01$) and diversity ($t_{8.0} = 3.0$, $P = 0.02$) indices (Fig. 2).

Using years as replicates, we found no difference between data sources in either the species richness ($t_{8.0} = 1.7$, $P = 0.13$) or Shannon diversity ($t_{8.0} = 1.0$, $P = 0.33$) of waterbirds (Fig. 3*a*). Likewise, for landbird species, eBird data did not detect significantly different species richness ($t_{8.0} = 2.1$, $P = 0.07$) or Shannon diversity ($t_{8.0} = 0.7$, $P = 0.50$; Fig. 3*b*) from the NSW surveys.

In total, 42 species recorded in the eBird data were not detected during the NSW surveys, and six species recorded during NSW surveys were not reported in eBird data. Of the 42 species detected solely in eBird data, 22 were detected once and eight were detected twice (Table S1). As such, multivariate analysis of variance identified a significant difference in avian community composition as determined by NSW surveys and eBird data ($R^2 = 0.21$, $P = 0.015$), but no difference among years for either dataset ($R^2 = 0.48$, $P = 0.065$; Fig. 4). A SIMPER analysis revealed that the difference in community structure was mostly due to species recorded more often in eBird data than in NSW surveys (Tables S1 and S2). For instance, tree martin, Australian reed-warbler, yellow thornbill, chestnut teal and great egret were the most influential species accounting for differences between data sources (Table S2), and they had 12, 21,

Table 1. Number of eBird and structured surveys conducted per year from June 2012 to June 2016 in Centennial Park, Sydney

Year	Number of surveys		Total minutes surveying	
	eBird	Structured area-search surveys	eBird	Structured area-search surveys
2012	3	38	650	570
2013	7	72	1764	1080
2014	34	42	3180	630
2015	66	52	8248	780
2016	68	38	8986	570

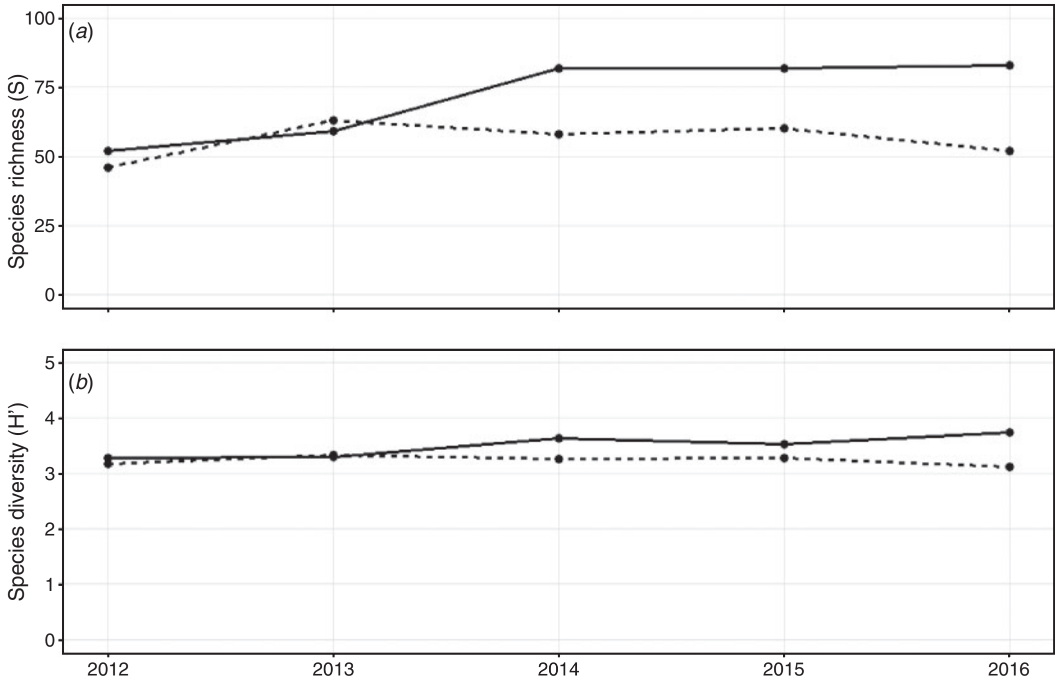

Fig. 1. Variation in (*a*) species richness and (*b*) Shannon diversity (H') from June 2012 to June 2016 in Centennial Park, Sydney, calculated from structured surveys (dashed line) and eBird data (continuous line).

19, 24 and 25 observations, respectively, in eBird data, compared with 0, 2, 1, 2 and 5 observations, respectively, in NSW surveys (Table S1). We found no clear patterns in the type of species more likely to be recorded with each survey method. However, nocturnal species (powerful owl, tawny frogmouth and barn owl) were recorded only in eBird surveys, which were also more likely to report common grassland birds (rock pigeon, European starling, little corella and long-billed corella).

Discussion

The bird diversity of a discrete urban greenspace, measured by species richness and Shannon diversity, was found to be higher using records collected through eBird than from structured surveys, but, after accounting for survey effort, structured surveys provided significantly higher estimates. This suggests that structured surveys may be a more efficient monitoring protocol (i.e. biodiversity estimates per unit time), but that eBird's inexpensive and easily collected data can provide higher biodiversity estimates (Munson *et al*. 2010). The higher estimates derived from eBird observations appear to reflect a combination of increased search effort (time spent surveying, Fig. 2) and spatial coverage (Fig. S1) compared with structured surveys. This exemplifies the inherent difference between structured and unstructured citizen science projects (Welvaert and Caley 2016). Furthermore, we found no differences in landbird and waterbird detection between data sources (Fig. 3), suggesting that eBirders do a job comparable to structured surveys for both bird classification types, contrasting with previous research which has found differences in detection and reporting among species' groups (Snäll *et al*. 2011).

Our analysis of community composition identified significant differences between the two survey methods, and was most influenced by differential reporting (i.e. significantly greater number of observations in the eBird data than NSW surveys) of a subset of species (Tables S1 and S2). This was likely due to the flexibility of eBird survey methods to allow exhaustive area searches, unconstrained by the replicated fixed-area searches of structured surveys, allowing for increased detection of uncommon birds that may only frequent a specific habitat of the greenspace (i.e. great egret, chestnut teal, yellow thornbill and Australian reed-warbler; Table S1). For example, nocturnally active birds were recorded by unstructured eBird surveys but not structured surveys (Table S1). eBird surveys probably targeted locations specifically known for roosting individuals, which had a low probability of occurrence within the areas of the structured surveys. Similarly, common grassland birds were detected more frequently in unstructured eBird surveys than structured surveys (Table S1), reflecting the increased spatial coverage of the eBird surveys (Fig. S1). Clearly, with its increased survey effort, eBird provided useful and possibly more accurate estimates of some biodiversity indices, despite the unstructured method of data collection. Conversely, by overestimating the importance of rare and/or cryptic species, eBird data may give exaggerated impressions of species abundance. Although calculation of abundance estimates was not attempted in this study (cf. Walker and Taylor 2017), we advise caution when considering rare species, and to ensure that data are fit for purpose. In regards to many forms of biodiversity monitoring, where land managers are interested in the full complement of species using a particular area, pseudo-replication of surveys (i.e. the same individual birds being observed and reported by multiple observers) is not an issue.

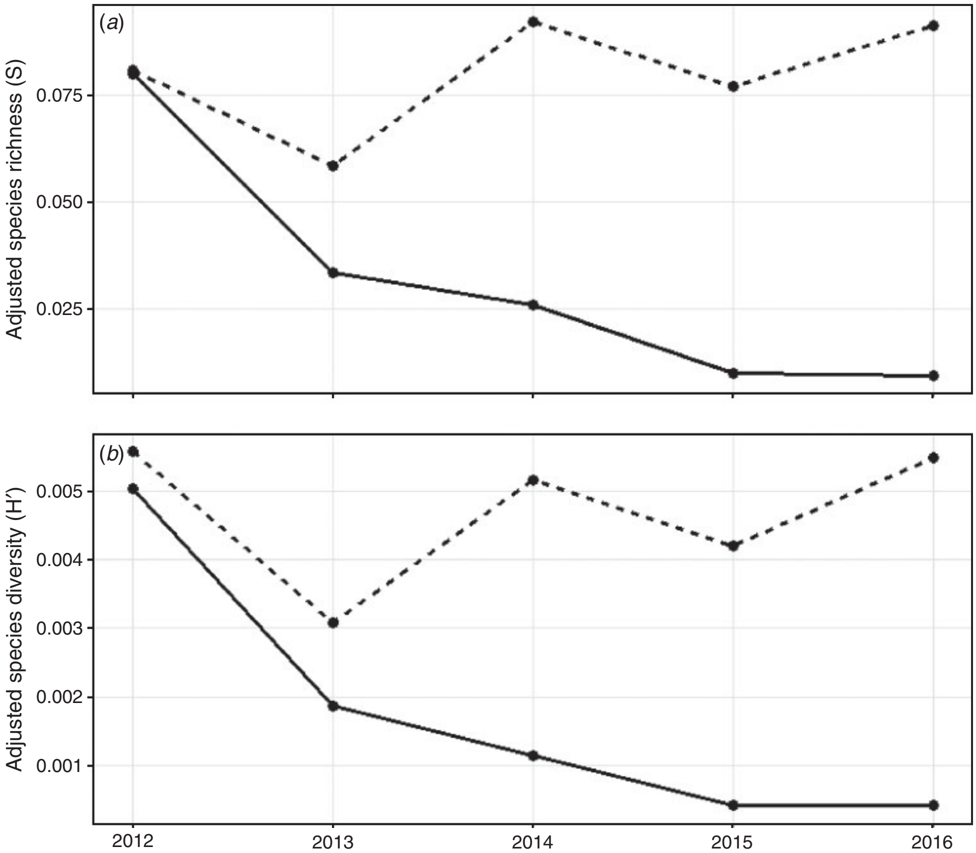

Fig. 2. Variation in (*a*) adjusted species richness and (*b*) adjusted Shannon diversity (H') from June 2012 to June 2016 in Centennial Park, Sydney, calculated from structured surveys (dashed line) and eBird data (continuous line). Species richness and diversity were adjusted by dividing them by total number of minutes spent surveying in that year.

Several studies have now investigated the validity of citizen-based bird data, both at large spatial scales (Snäll *et al*. 2011; Szabo *et al*. 2012; Kamp *et al*. 2016) and in case-specific instances (e.g. Nagy *et al*. 2012; Miller *et al*. 2016). Our analysis has shifted the traditional coarse-scale spatial focus (e.g. Munson *et al*. 2010; Kamp *et al*. 2016) of structured versus unstructured data to a fine spatial scale typically used by land managers and community groups (e.g. Callaghan and Gawlik 2015; Sullivan *et al*. 2017). We demonstrate that at small scales, land managers can be confident that eBird provides comparable and perhaps even better biodiversity estimates than structured surveys. Structured surveys, such as those compared here, usually involve stratification by habitat, and habitat classifications inevitably omit some low-occurrence or mixed habitats, and tend to under-sample extensive habitats. In our case, for example, results of structured surveys would have been better if some mixed-habitat roost sites had been included, or if there had been greater representation of grasslands. However, this would have entailed either increased survey effort or reduced sampling of core habitats.

Many land managers also want to track changes in abundance over time in relation to natural seasonal fluctuations or environmental change (Goldsmith 1991). Currently, eBird data may not adequately track absolute abundance at Centennial Park, due to the difficulties of extracting population estimates from checklist-based observational data (e.g. detectability estimation). Further, eBird data are likely to be less accurate at measuring relative densities of different species because search effort will vary with habitat type. As such, methods are needed to estimate absolute abundance using eBird (as opposed to relative abundance; Walker and Taylor 2017), and improve its application for conservation management. In addition, identification of the number of eBird surveys that are required for accurate community metrics is critical (i.e. how many lists are necessary; Bibby *et al*. 1998). For example, our avian community estimate, based on the eBird data for 2014–16, differed from that of 2012–13 (Fig. 4) when only 10 reports were submitted. From 2014 to 2016, 168 reports were submitted, a number sufficient to confidently describe composition. However, we note that this could partially be due to eBird officially replacing Eremaea birds in Australia in 2014 (http://ebird.org/content/australia/news/welcome-to-eremaea-ebird-2/ [Verified 27/03/2018]).

Our results showed that eBird surveys, collected by birdwatchers with a wider range of skills than that of experienced birdwatchers who conducted the structured surveys, were a useful source of data for describing the avifauna of an urban greenspace in Sydney. Further, the number of eBird checklists submitted for Centennial Park increased 10-fold during our study, potentially increasing their effectiveness in

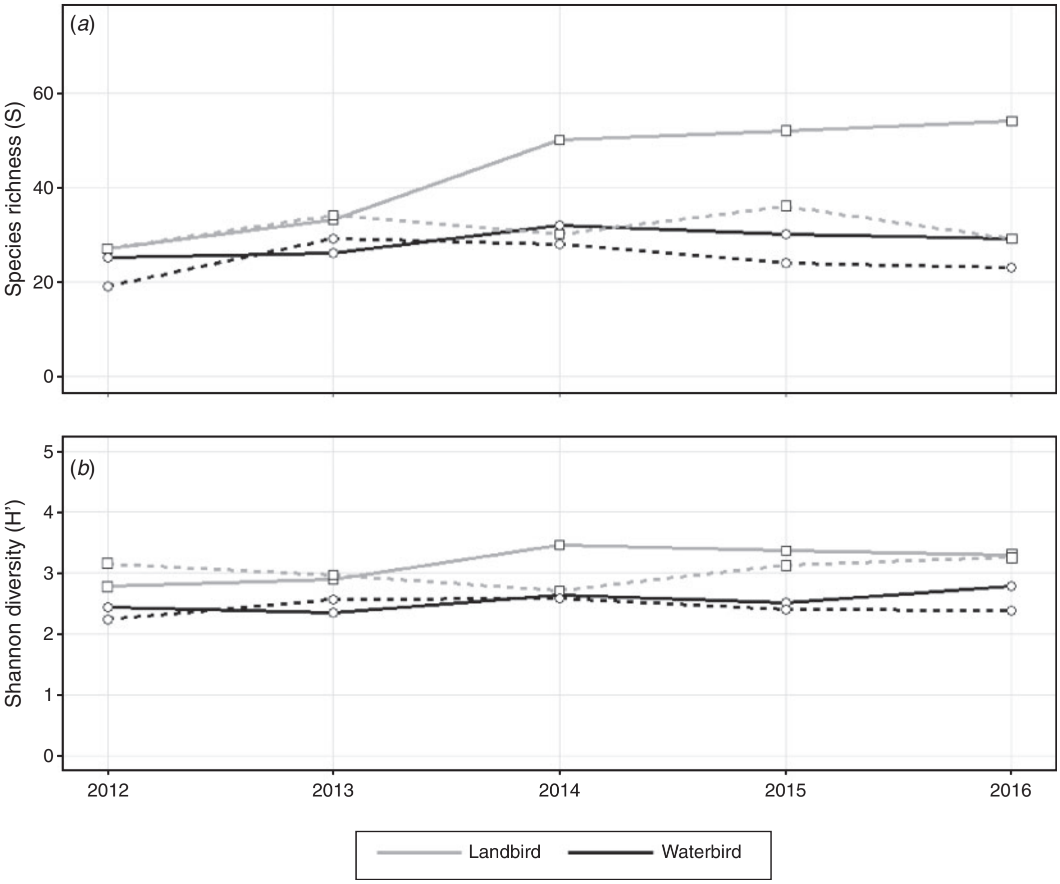

Fig. 3. Variation in (*a*) species richness and (*b*) Shannon diversity calculated from 2012 to 2016 at Centennial Park, Sydney, Australia, from structured surveys (dashed line) and eBird (continuous line). Richness and diversity were calculated separately for landbird and waterbird classifications.

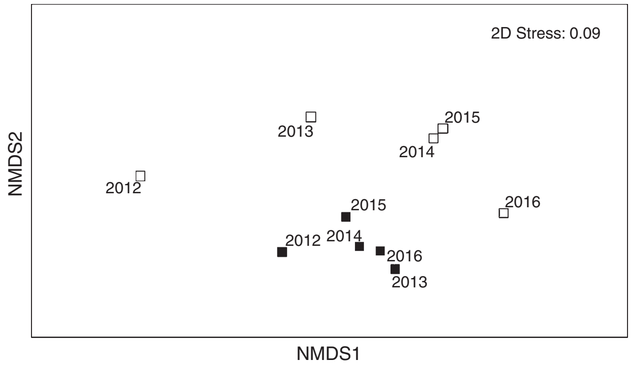

Fig. 4. Non-metric multidimensional scaling (NMDS) plot showing differences between avian communities, estimated using structured surveys (filled squares) and eBird data (open squares) from Centennial Park, Sydney, Australia, for each year from 2012 to 2016.

monitoring avian biodiversity. eBird has seen an exponential growth in use and number of contributors, and is now well established around the world (Sullivan *et al*. 2014). Submissions are likely to increase with the global rise in avitourism (Biggs *et al*. 2011; Steven *et al*. 2015) and increase in 'virtual birding' (Cottman-Fields *et al*. 2013), extending the reach of eBird data collection (Wood *et al*. 2011) to historically under-sampled regions. Ultimately, we demonstrate that an advantage of using eBird is the increased effort of citizen scientists, and validate biodiversity estimates when compared with structured surveys. Our study adds to the growing literature that is validating citizen science projects (Wiersma 2010; Bonter and Cooper 2012; Ellwood *et al*. 2017), but we focused on a small spatial scale. Our analyses have global implications for monitoring urban greenspaces and our results are likely generalisable across other taxa that may be the target of unstructured citizen science projects in urban greenspaces (Cooper *et al*. 2007).

Conflicts of interest

The authors declare no conflicts of interest.

Supplementary material

Supplementary materials include (1) the list of bird species recorded from each of the respective data sources, (2) the full results of the SIMPER analysis showing which species contributed to community differences, and (3) a figure showing the relationship between species richness and Shannon diversity and the distance travelled on a given eBird checklist. These materials are available from the Journal's website.

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Supplementary material

Avian monitoring – comparing structured and unstructured citizen science

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Table S1. The list of 122 bird species observed at Centennial Park, Sydney, Australia and the number of records from the eBird database and structured surveys, 2012–2016

Number of records refers to the number of times a species was recorded on a survey. Bird names follow eBird/Clements v2016 Taxonomy (http://www.birds.cornell.edu/clementschecklist/download/).

N = the number of surveys from the respective data sources

Species	Bird-type (W = Waterbird L = Landbird)	Number of Records	
		eBird (*N* = 178)	Structured Surveys (*N* = 242)
Black Swan (*Cygnus atratus*)	W	131	73
Magpie-lark (*Grallina cyanoleuca*)	L	127	60
Australian Magpie (*Gymnorhina tibicen*)	L	124	42
Australasian Swamphen (*Porphyrio melanotus*)	W	123	99
Australian Ibis (*Threskiornis moluccus*)	W	121	110
Australian Pelican (*Pelecanus conspicillatus*)	W	121	12
Crested Pigeon (*Ocyphaps lophotes*)	L	121	40
Dusky Moorhen (*Gallinula tenebrosa*)	W	121	118
Rainbow Lorikeet (*Trichoglossus haematodus*)	L	120	53
Pacific Black Duck (*Anas superciliosa*)	W	119	121
Eurasian Coot (*Fulica atra*)	W	116	103
Australian Raven (*Corvus coronoides*)	L	114	41
Rock Pigeon (*Columba livia*)	L	113	8
Noisy Miner (*Manorina melanocephala*)	L	111	186
Silver Gull (*Chroicocephalus novaehollandiae*)	W	110	29
Australasian Darter (*Anhinga novaehollandiae*)	W	109	49
Masked Lapwing (*Vanellus miles*)	W	108	11
Pied Cormorant (*Phalacrocorax varius*)	W	108	16
Welcome Swallow (*Hirundo neoxena*)	L	106	96
White-eyed Duck (*Aythya australis*)	W	105	60
Willie-wagtail (*Rhipidura leucophrys*)	L	105	38
Pied Currawong (*Strepera graculina*)	L	104	66
Superb Fairywren (*Malurus cyaneus*)	L	104	80
Common Myna (*Acridotheres tristis*)	L	103	43
Sulphur-crested Cockatoo (*Cacatua galerita*)	L	103	33
Little Corella (*Cacatua sanguinea*)	L	102	4
Great Cormorant (*Phalacrocorax carbo*)	W	100	38
Little Black Cormorant (*Phalacrocorax sulcirostris*)	W	99	52
Little Pied Cormorant (*Microcarbo melanoleucos*)	W	96	39
Spotted Dove (*Streptopelia chinensis*)	L	87	56
Laughing Kookaburra (*Dacelo novaeguineae*)	L	84	17
Long-billed Corella (*Cacatua tenuirostris*)	L	83	3
Australasian Grebe (*Tachybaptus novaehollandiae*)	W	80	64
Gray Butcherbird (*Cracticus torquatus*)	L	72	23
European Starling (*Sturnus vulgaris*)	L	70	4

White-faced Heron (*Egretta novaehollandiae*)	W	66	20
Powerful Owl (*Ninox strenua*)	L	64	3
Tawny Frogmouth (*Podargus strigoides*)	L	64	10
Gray Teal (*Anas gracilis*)	W	54	9
Maned Duck (*Chenonetta jubata*)	W	48	4
Buff-banded Rail (*Gallirallus philippensis*)	W	43	9
Yellow-tailed Black-Cockatoo (*Calyptorhynchus funereus*)	L	41	13
Intermediate Egret (*Mesophoyx intermedia*)	W	40	10
Royal Spoonbill (*Platalea regia*)	W	40	7
Rufous Night-Heron (*Nycticorax caledonicus*)	W	36	5
Red Wattlebird (*Anthochaera carunculata*)	L	33	25
Australasian Figbird (*Sphecotheres vieilloti*)	L	26	12
Black-faced Cuckooshrike (*Coracina novaehollandiae*)	L	25	15
Fairy Martin (*Petrochelidon ariel*)	L	25	17
Great Egret (*Ardea alba*)	W	25	5
New Holland Honeyeater (*Phylidonyris novaehollandiae*)	L	25	22
Chestnut Teal (*Anas castanea*)	W	24	2
Australian Reed-Warbler (*Acrocephalus australis*)	L	21	2
Channel-billed Cuckoo (*Scythrops novaehollandiae*)	L	20	9
Yellow Thornbill (*Acanthiza nana*)	L	19	1
Brown Goshawk (*Accipiter fasciatus*)	L	17	7
Cattle Egret (*Bubulcus ibis*)	W	16	4
Barn Owl (*Tyto alba*)	L	15	1
Tree Martin (*Petrochelidon nigricans*)	L	12	0
Pacific Koel (*Eudynamys orientalis*)	L	10	6
Collared Sparrowhawk (*Accipiter cirrocephalus*)	L	9	0
Gray Fantail (*Rhipidura albiscapa*)	L	9	6
Australian Kestrel (*Falco cenchroides*)	L	8	1
Silver-eye (*Zosterops lateralis*)	L	8	6
Galah (*Eolophus roseicapilla*)	L	7	0
Little Egret (*Egretta garzetta*)	W	7	0
Peregrine Falcon (*Falco peregrinus*)	L	7	0
Olive-backed Oriole (*Oriolus sagittatus*)	L	5	1
Pink-eared Duck (*Malacorhynchus membranaceus*)	W	5	5
Sacred Kingfisher (*Todiramphus sanctus*)	L	5	0
Spotted Pardalote (*Pardalotus punctatus*)	L	5	11
Eastern Spinebill (*Acanthorhynchus tenuirostris*)	L	4	1
White-bellied Sea-Eagle (*Haliaeetus leucogaster*)	L	4	0
Dollarbird (*Eurystomus orientalis*)	L	3	0
Eastern Rosella (*Platycercus eximius*)	L	3	0
Golden Whistler (*Pachycephala pectoralis*)	L	3	1
Gray Goshawk (*Accipiter novaehollandiae*)	L	3	1
House Sparrow (*Passer domesticus*)	L	3	0
Little Wattlebird (*Anthochaera chrysoptera*)	L	3	3

Musk Lorikeet (*Glossopsitta concinna*)	L	3	0
Rufous Fantail (*Rhipidura rufifrons*)	L	3	1
Australian Shelduck (*Tadorna tadornoides*)	W	2	0
Australian Shoveler (*Anas rhynchotis*)	W	2	3
Brown Quail (*Synoicus ypsilophorus*)	L	2	1
Eurasian Blackbird (*Turdus merula*)	L	2	0
Fan-tailed Cuckoo (*Cacomantis flabelliformis*)	L	2	1
Hoary-headed Grebe (*Poliocephalus poliocephalus*)	W	2	4
Latham's Snipe (*Gallinago hardwickii*)	W	2	0
Pied Stilt (*Himantopus leucocephalus*)	W	2	0
Red-whiskered Bulbul (*Pycnonotus jocosus*)	L	2	0
Scaly-breasted Lorikeet (*Trichoglossus chlorolepidotus*)	L	2	0
Southern Boobook (*Ninox novaeseelandiae*)	L	2	0
Spangled Drongo (*Dicrurus bracteatus*)	L	2	0
Straw-necked Ibis (*Threskiornis spinicollis*)	W	2	0
Australian King-Parrot (*Alisterus scapularis*)	L	1	0
Blue-billed Duck (*Oxyura australis*)	W	1	0
Brown Falcon (*Falco berigora*)	L	1	0
Brown Honeyeater (*Lichmera indistincta*)	L	1	0
Caspian Tern (*Hydroprogne caspia*)	W	1	0
European Greenfinch (*Chloris chloris*)	L	1	0
Lewin's Honeyeater (*Meliphaga lewinii*)	L	1	0
Mistletoebird (*Dicaeum hirundinaceum*)	L	1	0
Noisy Pitta (*Pitta versicolor*)	L	1	0
Pacific Heron (*Ardea pacifica*)	W	1	0
Red-browed Firetail (*Neochmia temporalis*)	L	1	0
Red-rumped Parrot (*Psephotus haematonotus*)	L	1	0
Rose Robin (*Petroica rosea*)	L	1	0
Rufous Whistler (*Pachycephala rufiventris*)	L	1	0
Striated Thornbill (*Acanthiza lineata*)	L	1	0
Variegated Fairywren (*Malurus lamberti*)	L	1	0
Weebill (*Smicrornis brevirostris*)	L	1	0
Whiskered Tern (*Chlidonias hybrida*)	W	1	0
Whistling Kite (*Haliastur sphenurus*)	L	1	0
Yellow-billed Spoonbill (*Platalea flavipes*)	L	1	0
Yellow-faced Honeyeater (*Caligavis chrysops*)	L	1	0
Yellow-rumped Thornbill (*Acanthiza chrysorrhoa*)	L	1	0
Australian Hobby (*Falco longipennis*)	L	0	1
Australian Kite (*Elanus axillaris*)	L	0	2
Black-fronted Dotterel (*Elseyornis melanops*)	W	0	1
Musk Duck (*Biziura lobata*)	W	0	1
Noisy Friarbird (*Philemon corniculatus*)	L	0	1
Plumed Whistling-Duck (*Dendrocygna eytoni*)	W	0	1

Table S2. The results of the SIMPER analysis, which demonstrates the species which most contributed to the difference in community composition

Species are listed in descending contribution. Bird names follow eBird/Clements v2016 Taxonomy

(http://www.birds.cornell.edu/clementschecklist/download/)

Species	Average	s.d.	Ratio	Cumsum	P
Tree Martin	0.006099	0.00319	1.915	0.0236	0.04
Australian Reed-Warbler	0.00535	0.00383	1.395	0.0444	0.17
Yellow Thornbill	0.00535	0.00383	1.395	0.0651	0.17
Chestnut Teal	0.004899	0.00416	1.178	0.0841	0.13
Great Egret	0.004899	0.00416	1.178	0.1031	0.13
Sacred Kingfisher	0.004759	0.00405	1.174	0.1215	0.03
European Starling	0.0047	0.00398	1.181	0.1397	0.15
House Sparrow	0.004656	0.00393	1.185	0.1578	0.04
Peregrine Falcon	0.004656	0.00393	1.185	0.1758	0.04
Brown Goshawk	0.004649	0.00428	1.085	0.1938	0.1
Silver-eye	0.004641	0.00427	1.086	0.2118	0.11
Maned Duck	0.004432	0.00408	1.086	0.229	0.48
Long-billed Corella	0.004397	0.00404	1.087	0.246	0.48
Olive-backed Oriole	0.004373	0.00402	1.089	0.263	0.35
Galah	0.004352	0.00364	1.197	0.2798	0.11
White-bellied Sea-Eagle	0.004352	0.00364	1.197	0.2967	0.11
Barn Owl	0.004202	0.00382	1.1	0.313	0.45
Powerful Owl	0.004054	0.00403	1.006	0.3287	0.97
Gray Fantail	0.003904	0.00419	0.932	0.3438	0.93
Australasian Figbird	0.00386	0.00416	0.929	0.3588	0.96
Channel-billed Cuckoo	0.003757	0.00436	0.861	0.3733	0.19
Pacific Koel	0.003757	0.00436	0.861	0.3879	0.19
Rufous Night-Heron	0.003755	0.00434	0.865	0.4024	0.26
Little Wattlebird	0.003736	0.00401	0.933	0.4169	0.98
Little Corella	0.003638	0.00422	0.862	0.431	0.95
Cattle Egret	0.003627	0.00422	0.86	0.4451	0.91
Dollarbird	0.003609	0.00453	0.797	0.459	0.01
Royal Spoonbill	0.003609	0.00453	0.797	0.473	0.01
Tawny Frogmouth	0.003609	0.00453	0.797	0.487	0.01
Spotted Pardalote	0.003571	0.00418	0.855	0.5009	0.33
Pink-eared Duck	0.00357	0.00418	0.854	0.5147	0.26
Australian Shoveler	0.00339	0.00394	0.861	0.5278	0.86
Fan-tailed Cuckoo	0.003377	0.00396	0.854	0.5409	0.84
Eastern Spinebill	0.00332	0.00385	0.862	0.5538	0.67
Rufous Fantail	0.003318	0.00384	0.863	0.5666	0.67
Australian Shelduck	0.003316	0.00421	0.788	0.5795	0.03
Golden Whistler	0.003312	0.00384	0.863	0.5923	0.68
Australian Kestrel	0.003306	0.00383	0.865	0.6051	0.56

Collared Sparrowhawk	0.003201	0.00404	0.793	0.6175	0.04
Little Egret	0.003201	0.00404	0.793	0.6299	0.04
Rock Pigeon	0.00314	0.00397	0.791	0.6421	0.42
Latham's Snipe	0.002909	0.00364	0.799	0.6534	0.11
Pied Stilt	0.002909	0.00364	0.799	0.6646	0.11
Red-whiskered Bulbul	0.002909	0.00364	0.799	0.6759	0.11
Spangled Drongo	0.002909	0.00364	0.799	0.6872	0.11
Eastern Rosella	0.002898	0.00363	0.799	0.6984	0.11
Musk Lorikeet	0.002898	0.00363	0.799	0.7096	0.11
Black-faced Cuckooshrike	0.002769	0.00414	0.669	0.7204	0.98
Gray Butcherbird	0.002769	0.00414	0.669	0.7311	0.98
White-faced Heron	0.002769	0.00414	0.669	0.7418	0.98
Hoary-headed Grebe	0.002593	0.0039	0.665	0.7519	0.49
Gray Goshawk	0.002489	0.00374	0.665	0.7615	0.93
Brown Quail	0.002397	0.00359	0.669	0.7708	0.96
Blue-billed Duck	0.001861	0.00381	0.489	0.778	0.03
Buff-banded Rail	0.001861	0.00381	0.489	0.7852	0.03
European Greenfinch	0.001861	0.00381	0.489	0.7925	0.03
Gray Teal	0.001861	0.00381	0.489	0.7997	0.03
Red-rumped Parrot	0.001861	0.00381	0.489	0.8069	0.03
Red Wattlebird	0.001861	0.00381	0.489	0.8141	0.03
Striated Thornbill	0.001861	0.00381	0.489	0.8213	0.03
Variegated Fairywren	0.001861	0.00381	0.489	0.8285	0.03
Weebill	0.001861	0.00381	0.489	0.8357	0.03
Eurasian Blackbird	0.001747	0.00357	0.489	0.8425	0.04
Pacific Heron	0.001747	0.00357	0.489	0.8493	0.04
Whiskered Tern	0.001747	0.00357	0.489	0.856	0.04
Pied Cormorant	0.001724	0.00355	0.486	0.8627	0.91
Fairy Martin	0.001638	0.00337	0.486	0.8691	0.93
Black-fronted Dotterel	0.001561	0.00321	0.486	0.8751	0.94
Plumed Whistling-Duck	0.001561	0.00321	0.486	0.8812	0.94
Australian Hobby	0.001536	0.00316	0.486	0.8871	0.96
Australian Kite	0.001501	0.00309	0.487	0.8929	0.96
Musk Duck	0.001501	0.00309	0.487	0.8988	0.96
Noisy Friarbird	0.001501	0.00309	0.487	0.9046	0.96
Brown Honeyeater	0.001454	0.00297	0.489	0.9102	0.11
Caspian Tern	0.001454	0.00297	0.489	0.9158	0.11
Lewin's Honeyeater	0.001454	0.00297	0.489	0.9215	0.11
Mistletoebird	0.001454	0.00297	0.489	0.9271	0.11
Rose Robin	0.001454	0.00297	0.489	0.9327	0.11
Scaly-breasted Lorikeet	0.001454	0.00297	0.489	0.9384	0.11
Whistling Kite	0.001454	0.00297	0.489	0.944	0.11
Yellow-billed Spoonbill	0.001454	0.00297	0.489	0.9497	0.11
Australian King-Parrot	0.001444	0.00295	0.489	0.9552	0.11

Brown Falcon	0.001444	0.00295	0.489	0.9608	0.11
Noisy Pitta	0.001444	0.00295	0.489	0.9664	0.11
Red-browed Firetail	0.001444	0.00295	0.489	0.972	0.11
Rufous Whistler	0.001444	0.00295	0.489	0.9776	0.11
Southern Boobook	0.001444	0.00295	0.489	0.9832	0.11
Straw-necked Ibis	0.001444	0.00295	0.489	0.9888	0.11
Yellow-faced Honeyeater	0.001444	0.00295	0.489	0.9944	0.11
Yellow-rumped Thornbill	0.001444	0.00295	0.489	1	0.11
Australasian Darter	0	0	NaN	1	1
Australasian Grebe	0	0	NaN	1	1
Australasian Swamphen	0	0	NaN	1	1
Australian Ibis	0	0	NaN	1	1
Australian Magpie	0	0	NaN	1	1
Australian Pelican	0	0	NaN	1	1
Australian Raven	0	0	NaN	1	1
Black Swan	0	0	NaN	1	1
Common Myna	0	0	NaN	1	1
Crested Pigeon	0	0	NaN	1	1
Dusky Moorhen	0	0	NaN	1	1
Eurasian Coot	0	0	NaN	1	1
Great Cormorant	0	0	NaN	1	1
Intermediate Egret	0	0	NaN	1	1
Laughing Kookaburra	0	0	NaN	1	1
Little Black Cormorant	0	0	NaN	1	1
Little Pied Cormorant	0	0	NaN	1	1
Magpie-lark	0	0	NaN	1	1
Masked Lapwing	0	0	NaN	1	1
New Holland Honeyeater	0	0	NaN	1	1
Noisy Miner	0	0	NaN	1	1
Pacific Black Duck	0	0	NaN	1	1
Pied Currawong	0	0	NaN	1	1
Rainbow Lorikeet	0	0	NaN	1	1
Silver Gull	0	0	NaN	1	1
Spotted Dove	0	0	NaN	1	1
Sulphur-crested Cockatoo	0	0	NaN	1	1
Superb Fairywren	0	0	NaN	1	1
Welcome Swallow	0	0	NaN	1	1
White-eyed Duck	0	0	NaN	1	1
Willie-wagtail	0	0	NaN	1	1
Yellow-tailed Black-Cockatoo	0	0	NaN	1	1

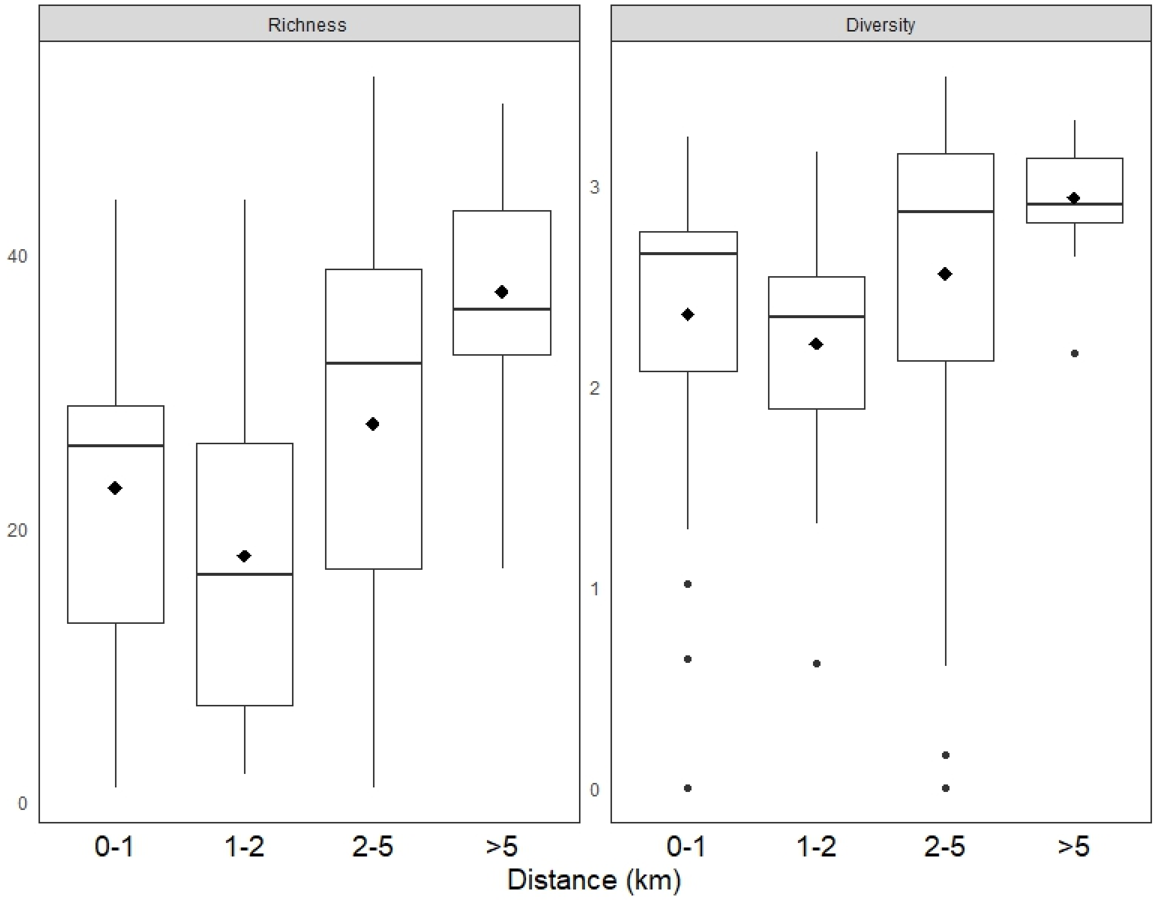

Fig. S1. The average (dark triangle) species richness and Shannon diversity calculated from an eBird checklist placed in distance bins, based on the reported distance travelled per checklist, using 178 eBird checklists between June 2012 – June 2016. As the distance travelled by an eBirder increases, there is a general increase with both richness and Shannon diversity.