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Insights into human-wildlife interactions in cities from bird sightings recorded online

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ABSTRACT

Interactions with nature can improve the wellbeing of urban residents and increase their interest in biodiversity. Many places within cities offer opportunities for people to interact with wildlife, including open space and residential yards and gardens, but little is known about which places within a city people use to observe wildlife. In this study, we used publicly available spatial data on people's observations of birds from three online platforms—eBird, iNaturalist, and Flickr—to determine where people observe birds within the city of Chicago, Illinois (USA). Specifically, we investigated whether land use or neighborhood demographics explained where people observe birds. We expected that more observations would occur in open spaces, and especially conservation areas, than land uses where people tend to spend more time, but biodiversity is often lower (e.g., residential land). We also expected that more populated neighborhoods and those with higher median age and income of residents would have more bird observations recorded online. We found that bird observations occurred more often in open spaces than in residential areas, with high proportions of observations in recreation areas. In addition, a linear regression model showed that neighborhoods with higher median incomes, those with larger populations, and those located closer to Lake Michigan had more bird observations recorded online. These results have implications for conservation and environmental education efforts in Chicago and demonstrate the potential for social media and citizen science data to provide insight into urban human-wildlife interactions.

1. Introduction

With over half of the world's population residing in cities (United Nations, 2015) and an increasing amount of time spent in front of screens, many people are becoming disconnected from the natural world. This phenomenon is termed the "extinction of experience" (Miller, 2005; Pyle, 1993). Urban green spaces such as parks and gardens can help to counter this effect, by harboring biodiversity and providing opportunities for people to interact with nature (Dearborn & Kark, 2010; Soga & Gaston, 2016). Access to urban green space is considered to be important from a public health perspective because of its potential to increase wellbeing via reductions of air pollutants (Nowak et al., 1998); opportunities for exercise, recreation, and community building (Arnberger & Eder, 2012; Bjork et al., 2008; Krefis, Augustin, Schlünzen, Oßenbrügge, & Augustin, 2018); and stress reduction (Grahn & Stigsdotter, 2010). In addition, there is some evidence that exposure to higher biodiversity can produce even greater increases in wellbeing (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007; Grahn & Stigsdotter, 2010; Maller, Townsend, Pryor, & Brown, 2006).

A city offers many places for people to experience nature. Often, much of the green space in cities is contained in public parks and home gardens (Evans, Newson, & Gaston, 2009). In some cities, residential neighborhoods contain the majority of tree cover (Daniel, Morrison, & Phinn, 2016; Shanahan, Lin, Gaston, Bush, & Fuller, 2014) and higher plant density and/or diversity (Clarke, Jenerette, & Davila, 2013; Threlfall et al., 2016) than other parts of the city. Furthermore, home gardens are sites where many people interact with biodiversity, such as wild birds visiting bird feeders (Carver, 2013; Clucas, Rabotyagov, & Marzluff, 2015), and are a preferred space for children to experience nature (Hand et al., 2017). Yet public green spaces such as parks provide opportunities for more people to observe nature, particularly those without access to home gardens. Large public green spaces may also contain plant and animal species that are absent from smaller, private lots, including species specialized to certain habitats, such as wetlands (Aronson et al., 2017; Williams et al., 2009). Within cities, residents and managers may recognize particular green spaces as providing significant opportunities for human-nature interactions, but the relative importance of different types of green spaces for providing these opportunities at larger scales (i.e., across cities) is unknown. This question could have implications for prioritizing and managing green spaces in cities.

Birds offer one of the most promising ways for people to observe and

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interact with biodiversity in cities (U.S. Department of the Interior, U.S. Fish and Wildlife Service, U.S. Department of Commerce, & U.S. Census Bureau, 2016). In addition to being highly visible, birds are often more abundant in cities and suburbs than in rural areas, if sometimes less diverse (Blair, 1996). While some people have negative attitudes towards birds, especially towards particular species (Belaire, Westphal, Whelan, & Minor, 2015; Cox et al., 2018), many people enjoy listening to or watching birds, as is evidenced by the multi-billion-dollar birdwatching industry in the U.S. alone (Carver, 2013). According to a report from the U.S. Fish and Wildlife Service on birdwatching in the U.S. (Carver, 2013), older people, white people, and those with higher income and educational attainment were more likely to regularly observe birds at home or travel at least one mile to observe a bird. Less is known about "incidental" observations of birds (i.e., those that occur unintentionally while participating in another activity (Keniger, Gaston, Irvine, & Fuller, 2013; Cox, Hudson, Shanahan, Fuller, & Gaston, 2017)), which may be an important mechanism for human-nature interactions in cities (Beery et al., 2017).

People may appreciate birds for a number of different reasons. These include aesthetic value from seeing or hearing birds, a sense of place linked to seeing or hearing familiar species, spiritual experiences, opportunities to teach children or learn about nature, and (for many birders) the opportunity to add another species to a "life list" (Belaire et al., 2015; Mcfarlane, 1994; Soga, Gaston, Koyanagi, Kurisu, & Hanaki, 2016). Different areas across a city provide opportunities for people to interact with and appreciate birds in different ways. However, there has been little research on human-wildlife interactions (especially positive interactions) in cities, so not much is known about who receives benefits from interacting with birds and where these interactions occur (Soulsbury & White, 2015).

Advances in internet technology are opening new opportunities for research on human-wildlife interactions. For example, some data on where people observe birds are now publicly available, in the form of spatially explicit bird observations that people record on the internet. eBird is a prominent example of an online platform where thousands of people record observations of birds for the purposes of personal record keeping, enhancing scientific understanding of bird species dynamics, and contributing to conservation efforts (Wood, Sullivan, Iliff, Fink, & Kelling, 2011). In addition to eBird, other platforms for recording biodiversity observations online have emerged in recent years. One of the largest is iNaturalist, a social networking site where individuals upload photographs of the organisms they observe and can outsource species identification to their network of followers. Some other social networking sites that are not explicitly aimed at biodiversity records, such as the photo-sharing platform Flickr, also contain biodiversity observations. Scientists have recently recognized the potential for these various online platforms, including social networking sites such as Flickr and Twitter, to supplement more traditional sources of data for biodiversity science and conservation (Daume, 2016; Hausmann et al., 2017; Roberge, 2014; Tenkanen et al., 2017), such as information on wildlife viewing (Mancini, Coghill, & Lusseau, 2018a). However, to our knowledge, no study has made use of these data sources for identifying sites of human-wildlife interactions in cities.

In this paper, we examined human-wildlife interactions in Chicago, Illinois (USA), using data on bird observations from eBird, iNaturalist, and Flickr to ask where these observations occur. First, we were interested in determining which land uses are most important for providing opportunities for people to observe birds in the city. We compared land uses that likely differ in their perceived conservation value and levels of accessibility: conservation areas, other types of open space (e.g., golf courses, cemeteries), residential areas, water bodies, and roadways and rights-of-way. We expected that the majority of people would observe birds in open space, and especially in conservation areas such as nature reserves, where there tends to be higher bird diversity (Ortega-Álvarez & MacGregor-Fors, 2009) and where people may specifically go to see birds. In contrast, we expected that fewer people would observe birds in land uses where people generally spend more time but tend to have lower bird diversity, such as residential areas. Second, we examined differences in the number of bird observations made in different neighborhoods in relation to neighborhood characteristics, including socioeconomic factors. We expected that more populated neighborhoods and those with higher median age and income of residents would have more bird observations recorded online, because older and wealthier individuals are more likely to participate in birdwatching (Carson, 2013). This study provides information on popular locations and gaps of bird observations in Chicago, with implications for conservation and education efforts.

2. Methods

2.1. Study site

Chicago is the third largest city in the United States with a population of 2,695,598 at the 2010 census (U. S. Census Bureau, 2010). The city sits in the transition zone between the eastern deciduous forests and the tall grass and mixed grass prairies of the central United States. It experiences a humid continental climate with four distinct seasons. The eastern boundary of the city is Lake Michigan, one of the largest freshwater lakes in the world (Fig. 1). Chicago has an extensive waterfront, including a 29 km-long publicly accessible lakefront trail.

2.2. Data acquisition - bird observations

In January 2018, we acquired data on bird observations from three citizen science and social media platforms: eBird, iNaturalist, and Flickr. We selected these platforms because they contain bird observations and are available for public download. In addition, we expected that combining data from these three platforms would offer a more complete picture of the bird observations that people record online, since they presumably have different user groups and different aims (e.g., record-keeping, learning new species, and sharing photographs). For all three datasets, we obtained data on observations made between January 1, 2015 and December 31, 2017. This two-year time period was selected to provide some inter-annual variation and sufficient data across years from all three platforms. We selected only georeferenced observations (i.e., those with an associated latitude and longitude). Specific information about each online platform and methods for accessing data from each are described below (and see Appendix A for a comparison of the data available from each platform).

eBird is a citizen science project devoted to documenting the global distribution of birds. More than 100 million bird sightings are contributed to the database each year, making it the world's largest biodiversity-related citizen science project (https://ebird.org/about). eBird is a tool for birders to keep track of their observations and find places to view species of interest using interactive maps (Wood et al., 2011). In addition, eBird has been used in research on bird populations and migration (Hurlbert & Liang, 2012; La Sorte et al., 2014; Walker & Taylor, 2017), as well as to inform species conservation (Sullivan et al., 2009, 2017). Contributors to the site record observations by entering the name of the species they saw or heard, the location (using GPS coordinates or choosing the location on an online map), and the date and time of the observation, along with optional additional information. We requested the Basic Dataset of bird observations from Illinois, directly from eBird (2018).

eBird observations are classified based on the amount of search effort and the data collection method, since many contributors use standardized protocols to increase comparability across records for use in scientific research. Observation types include 'incidental observations', 'stationary counts', 'traveling counts', and 'area counts'. For this study, we used observations classified as 'incidental' (previously designated by eBird as 'casual' observations), 'stationary', and 'traveling'. 'Stationary' and 'traveling' counts are recorded with information on the

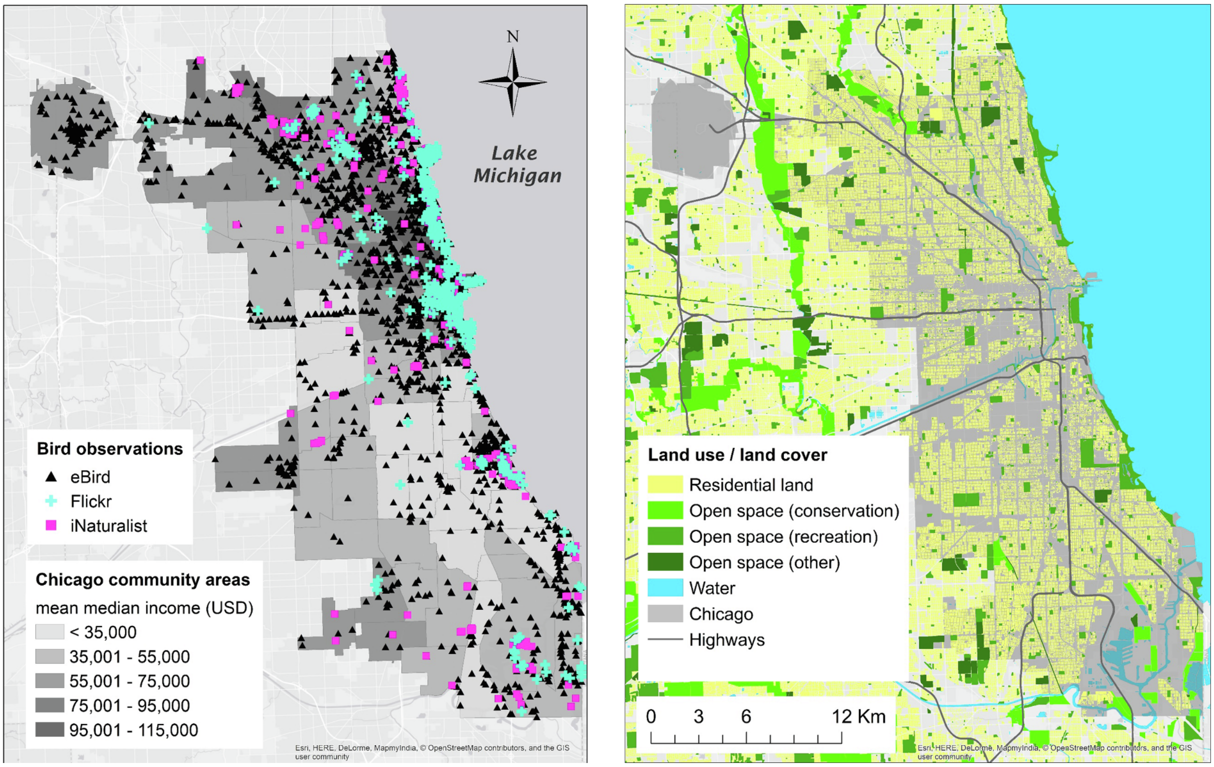

Fig. 1. Map of bird observations from the three web platforms (Flickr, eBird, and iNaturalist) across the city of Chicago, in relation to mean median income of community areas (left panel) and open space, residential land use, highways, and waterways (right panel).

amount of time spent recording bird observations (‘stationary’) or the distance covered while observing birds (‘traveling’), while ‘incidental’ observations on eBird are collected without a standard protocol. We did not include ‘area’ counts in this study as these involve surveying an entire site for birds and are more likely to be carried out specifically for research. We also filtered the eBird data to include only observations that were entered as a specific location by an individual user or were mapped to an existing birding ‘hotspot’ location (i.e., a site visited by multiple eBird users), excluding observations that were assigned point coordinates corresponding to a larger spatial unit (e.g., city, county) rather than a specific location.

iNaturalist is an online social network with over 750,000 members, where participants can share photographs of any organism they observe in nature (https://www.inaturalist.org). iNaturalist also functions as a crowdsourced species identification system: participants upload photographs of their observations, and other participants can suggest or confirm species identifications. We downloaded observations (which consisted of a species names, the location, date, and time of the observation, and a URL link to the image, among other information) from the iNaturalist Application Programming Interface (API) using the ‘rinat’ package (Barve & Hart, 2017) in R (R Core Development Team, 2018). We selected bird observations in the API query by specifying the taxon name ‘Aves’, including ‘research grade’ observations as well as others whose species identification has not been identified by an expert. Some iNaturalist observations have obscured spatial coordinates, meaning that they are assigned a random location from within a 0.2 × 0.2 degree cell (i.e., over 100 km × 100 km; https://www.inaturalist.org/pages/geoprivacy); these observations were filtered out of our dataset. In addition, iNaturalist provides information on the accuracy of the location coordinates. We thus filtered the iNaturalist data to include only observations with a location accuracy of 50 m or less. We also removed observations that were coded as ‘captive or cultivated’, to ensure that we were only including observations of wild birds.

Flickr is a social network and photo sharing platform that hosts more than 10 billion images (https://www.flickr.com/). Unlike eBird and iNaturalist, Flickr is not explicitly targeted toward nature enthusiasts. However, many nature enthusiasts take photographs of nature and upload their photos to the Flickr website. Flickr photos are accompanied by optional metadata such as photo title, location (latitude and longitude), date, and textual tags. We accessed the Flickr API using the ‘RCurl’ package in R (Lang, 2016) and code adapted from Mancini et al. (2018a), filtering observations to those with the highest location accuracy level (‘street level’). We used the ‘text’ search to extract photos with the word ‘bird’ in their tags, title, or description. Then we viewed one photo per user per day (to avoid double-counting photos of the same subject; Mancini et al., 2018a) in a Shiny app in R (using the ‘shiny’ package (Chang, Cheng, Allaire, Xie, & McPherson, 2018)), and manually removed photos that did not include a visible bird or that focused on a captive or domesticated bird.

After downloading the data, we clipped observations to the Chicago city boundary using the ‘Clip’ tool in ArcGIS version 10.4 (ESRI, 2016). We also included observations that occurred within a 150 m buffer into Lake Michigan (using the ‘Buffer’ tool in ArcGIS), to include nearshore observations as well as those occurring on jetties and beaches, which did not overlap with the city boundary layer. We filtered each dataset to include only one observation per person per location, by removing observations located within 100 m of any other observation made by the same individual. We chose this filtering method because we were interested in explaining which places the most individuals use to observe birds, rather than places where a few individuals observe birds frequently, such as a single backyard.

2.3. Data acquisition - geographic and socioeconomic data

We obtained land use data from the Chicago Metropolitan Agency for Planning (CMAP) 2013 Land Use Inventory dataset (Agency, 2016). As we were interested in the importance of land uses with different perceived conservation value and accessibility for providing opportunities for bird observations, we condensed the original 60 land uses

Table 1
Means and ranges of community area attributes used as predictor variables in linear model predicting the number of bird observations recorded in each community area.

Predictor variable	Definition	Mean (Range)
Total land area	Total area (km^2) of the community area	7.77 (1.57–34.55)
Distance to lake	Minimum distance (km) from community area boundary to Lake Michigan	4.68 (0–14.66)
Proportion residential area	Proportion of land classified as residential	0.331 (0.027–0.577)
Proportion open space area	Proportion of land classified as open space	0.083 (0.003–0.359)
Median income	Mean of median income values from constituent census tracts (U.S. dollars)	49,282 (23,199 – 102,750)
Total population	Sum of population estimates from constituent census tracts	78,282 (20,149 – 212,676)
Median age	Mean of median age values from constituent census tracts (years)	35.6 (28.8–45.6)

classes to the following seven classes (Appendix B): (1) open space primarily for conservation purposes (e.g., forest preserves), (2) open space primarily for recreation purposes (including golf courses), (3) other open spaces (including trails/greenways and cemeteries), (4) water, (5) single family residential (including detached and attached residences and mobile homes), (6) multifamily residential, (7) roadway and right-of-way, (8) all other land uses. Open space primarily for conservation purposes is defined in CMAP as open space with less than 50% of the land area in impervious surface/managed turf and includes county forest preserves as well as local parks that are primarily in a natural state.

To evaluate the importance of neighborhood characteristics on birding activity, we divided the city according to the 77 Chicago Community Areas. These community divisions were defined by the University of Chicago's Social Science Research Committee in the 1920s (Burgess & Newcomb, 1931), are officially recognized by the city, and are tied to U.S. census data. We used seven predictor variables describing geographic and socioeconomic characteristics of community areas that could influence how many people recorded bird observations online within them (Table 1). We obtained socioeconomic data on median household income, median age, and total population from the U.S. Census's 2016 American Community Survey five-year estimates (U.S. Census Bureau, 2016) at the census block level. This data was used to calculate the mean income, mean age, and total population of each community area from its constituent census tracts. We chose these variables because we expected that more densely populated community areas would have more bird observations recorded online, and because older and wealthier people tend to be more frequent participants in birdwatching activities (Carver, 2013). We also expected that larger community areas and those with more open space would provide more bird observations. Thus, we calculated the total land area and the proportion of land area in residential and in open space land uses, respectively, of each community area. Finally, we calculated the minimum distance from each community area to Lake Michigan using the 'Near' tool in ArGIS, because the lake and nearby downtown area are major city attractions, and thus neighborhoods close to the lake may have more bird observations.

2.4. Data analysis

To understand the distribution of observations across different land use types, we calculated the proportion of observations in each of the seven land use categories listed above, using the 'over' function in the 'sp' package (Pebesma & Bivand, 2005) in R. We used a Fisher's test ('fisher.test' function in R) to determine whether the distribution of all observations (combined over the three platforms) differed from the proportional area of each land use type. Then we used a second Fisher's test to determine whether the distribution of observations across land use types differed between the three platforms. We performed post-hoc pairwise Fisher's tests for individual land use categories to determine which land uses contributed to differences in overall distributions.

In order to investigate the effect of community area socioeconomic and geographic characteristics on the distribution of bird observations, we fit a Bayesian generalized linear model using the 'rjags' package in R (Plummer, 2018). The model predicted the total number of bird observations in each community area (summed over all three platforms) based on the seven neighborhood-level predictor variables described above. We removed bird observations from the community-area-level analysis that were located within 25 m of highways or on water bodies, since we expected that these observations are less likely to depend on the characteristics of the community areas themselves. The number of bird observations per community area was fit using a Poisson distribution with an extra variance term to account for overdispersion (tested using the 'dispersiontest' function in the 'AER' package in R (Kleiber & Zeileis, 2008)). We used a single variance term for estimating all parameters to prevent model overfitting (Gelman, Stern, Carlin, Dunson, & Vehtari, 2013) and used uninformative priors for all parameters (mean of zero, standard deviation of 1000). We ran three Monte Carlo Markov chains for 520,000 iterations with 20,000 used for burn-in and a thinning parameter of 1. To assess model fit, we used a Bayesian p-value comparing the sums of squares of differences of the observed and simulated data for the mean, and we used the Gelman and Rubin's statistic to assess model convergence. We tested for spatial autocorrelation in the model residuals with Moran's I using the 'spdep' package in R (Bivand & Wong, 2018), run with 999 simulations. All predictor variables were centered and scaled by one standard deviation prior to analysis, and we tested for bivariate correlations between predictors prior to fitting the model.

We expected that filtering the observation data to one observation per person per location could influence the results of the analyses, particularly by downplaying the importance of certain land uses, such as residential areas, where a few individuals may frequently observe birds (e.g., at backyard bird feeders). In order to test the effects of this filtering choice, we ran the analyses described above on a second dataset of observations filtered to one observation per visit to a location (i.e., one observation per person per location per day.

3. Results

Initially, we acquired 629,807 bird observations from eBird, 3981 Flickr photos tagged with 'bird' (not all of which were actually photos of birds), and 1307 bird observations from iNaturalist. When we filtered each bird observation dataset to include only one observation per person per location, there were 7944 observations from eBird, 474 observations from iNaturalist, and 561 observations from Flickr (Fig. 1). Of the 8979 total observations, slightly more than half occurred in open space, with 39% occurring in recreation areas and 8% in conservation areas (Fig. 2). Only 4% of observations occurred in residential areas, with most of these occurring in areas with multi-family homes. About 14% of observations occurred on roadways and rights-of-way, and 10% on water. The distribution of bird observations across land uses was significantly different from the distribution of land area in different land uses (simulated p-value < 0.001). There was a much higher proportion of observations recorded in open spaces than land area in open space (odds ratio 6.82, $p < 0.001$) and a much lower proportion of observations recorded in residential areas than land area

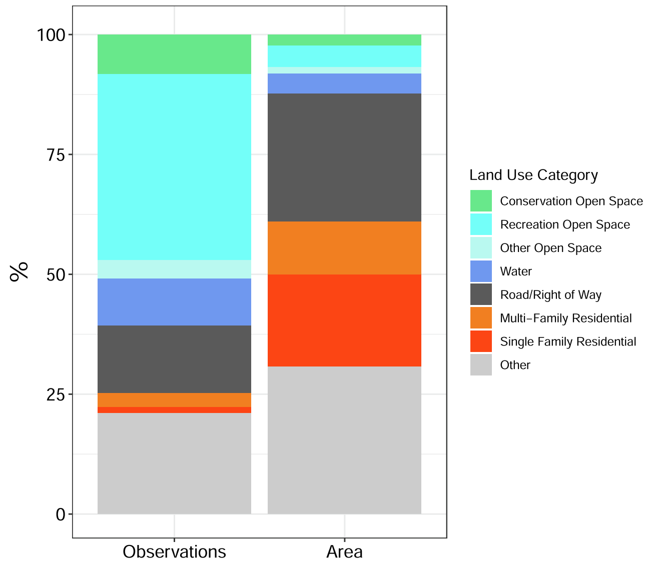

Fig. 2. Proportions of observations recorded in different land uses, compared to the proportions of area contained in the different land use categories in Chicago (including a 150 m buffer around the city into Lake Michigan). There was a significant difference between the two distributions (simulated p-value < 0.001), including between the proportions of observations and area in open space and in residential land uses (Appendix C).

in residential land uses (odds ratio 0.18, $p < 0.001$; see Appendix C, Table C1 for results of pairwise Fisher's tests).

There were some interesting and significant differences between the land uses of bird observations on the three platforms (simulated p-value < 0.001; Fig. 3). Of the three platforms, eBird had the smallest proportion of observations in multi-family residential areas, while Flickr had the largest proportions in recreational areas and on water and the smallest proportion in conservation areas (Appendix C, Table C2). eBird had a larger proportion of observations on roadways and rights-of-way than Flickr (odds ratio = 1.62, $p < 0.001$); many of these observations occurred on highways (Fig. 1). Only eBird and iNaturalist differed in the proportion of observations in residential areas

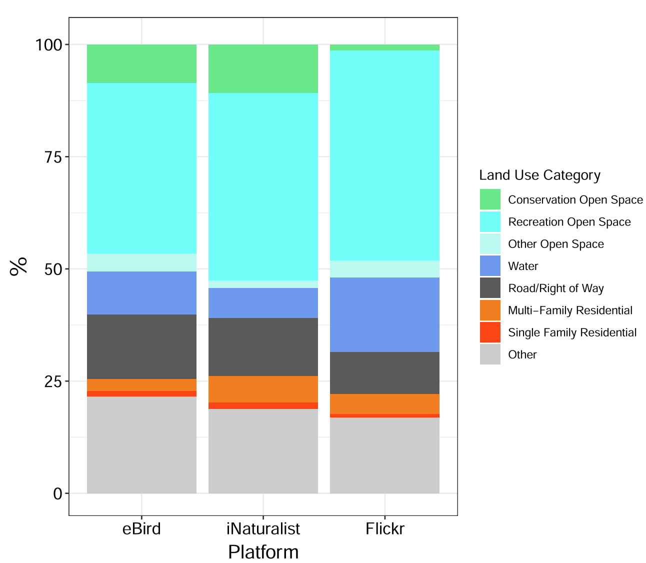

Fig. 3. Proportions of observations recorded in different land uses on the three different online platforms (n = 7944 eBird; n = 474 iNaturalist; n = 561 Flickr). There was a significant difference between the three distributions (simulated p-value < 0.001), including in the proportions of observations in conservation, recreation, and residential land uses (Appendix C).

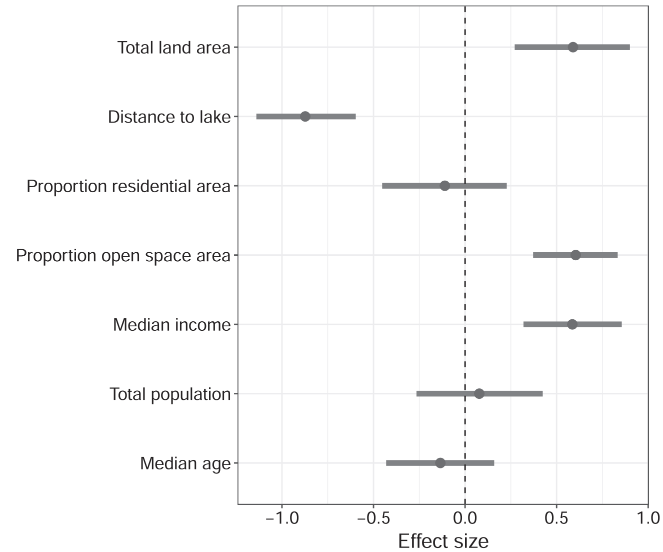

Fig. 4. Means and 95% credible intervals of posterior distributions for parameters in Bayesian generalized linear model predicting the number of bird observations recorded on online platforms across community areas.

overall, with a larger proportion recorded on iNaturalist than on eBird (odds ratio = 0.51, $p < 0.001$). The three platforms did not significantly differ in the proportion of observations recorded in all open spaces or in single-family residential areas. See Appendix C for results of pairwise Fisher's tests for individual land use categories.

After removing observations occurring on water bodies and along highways, there were 8782 bird observations included in the regression analysis (7755 observations from eBird, 471 from iNaturalist, and 556 from Flickr). The number of observations per community area ranged from zero to 1040, with a mean of 109. The regression results showed that there were fewer observations in community areas farther from Lake Michigan and more observations in larger community areas, those with a higher proportion of land area in open space, and those with higher median income (Fig. 4). There was no measurable effect of resident age, population size, or the proportion of residential land area on the number of observations in different community areas. The model converged with a Gelman and Rubin's statistic less than 1.01 for all parameters (Gelman & Rubin, 2007), and appeared to adequately predict the data (Bayesian p-value = 0.500; Appendix D). There was no significant spatial autocorrelation in the model residuals (Moran's I = -0.031, p = 0.563). Correlations between predictor variables were all less than 0.5.

When we compared these results to those from a dataset of observations filtered to one observation per visit to a location (i.e., a less restrictive filtering rule that allows multiple observations from the same observer at the same location), we found that the less restrictive filtering rule led to an increase in the proportion of observations recorded in open space (both conservation and recreation) and in single-family residential areas, and decreased the proportion recorded on water and roadways. However, these differences did not substantially change the relative importance of open space versus residential areas for bird observation, or the effects of predictors in the linear regression (Appendix E).

4. Discussion

We found evidence that people are observing birds in a wide range of land uses and neighborhoods across Chicago. Open spaces, especially recreation areas, appear to be important locations for bird observation in Chicago (Fig. 2). However, other land uses such as water and roadways also provided opportunities for people to observe birds, suggesting that incidental observations could be an important mechanism for human-wildlife interaction in cities (Cosquer, Raymond, & Prevot-Julliard, 2012; Cox et al., 2017). We also observed spatial patterns in bird observations across neighborhoods, with fewer observations in low-income community areas and those with less open space, as well as those farther from Lake Michigan (Fig. 4). These results suggest some potential opportunities for increasing positive human-wildlife interactions, which we discuss below.

The importance of open space for bird observations in our dataset, particularly in comparison to residential areas, suggests that more people make bird observations while out in the city than at home. However, there are several reasons why residential areas may be underrepresented in our dataset. First, while residential land use is extensive, it provides less green space in which to observe birds than other land uses with fewer built surfaces. Second, our method for filtering the bird observation data to one observation per person per location removed some observations of birds at single-family residences (mostly recorded on eBird; Appendix E). Finally, some iNaturalist observations in residential areas had obscured locations—likely due to privacy concerns by its users—and so were excluded from our analyses. Thus, the data suggest that residential areas can be very important locations for urban bird observation for some individuals, such as those who regularly monitor birds on their property, but are less important than open space for providing bird-observing opportunities for many people.

The use of open space for observing birds was also evident at the neighborhood scale, with more observations recorded in community areas with more open space. Neighborhoods with more open space may attract more birdwatchers, or may host more birds or more diverse bird communities (Loss, Ruiz, & Brawn, 2009). The importance of accessible open space for interactions with nature suggests that maintaining open spaces across neighborhoods, and creating open spaces in neighborhoods lacking them, can increase human-nature interactions and possibly residents' wellbeing (Barbosa et al., 2007; Colléony, Prévot, Saint Jalme, & Clayton, 2017; Soga et al., 2015). It is particularly important to increase the accessibility of green spaces and create equitable opportunities for people to recreate and experience nature close to where they live and work (Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Rigolon, 2016). In Chicago, low- to mid-income Hispanic neighborhoods tend to have less access to open space, tree cover, and bird biodiversity than other neighborhoods, suggesting that lack of access to open space could constitute an environmental justice issue (Davis et al., 2012). In addition to creating open space, "greening" programs to promote native species and provide wildlife habitat on private lands are another potential mechanism for providing more equitable opportunities for nature experiences in cities (Shanahan et al., 2014).

Notably, most of the observations in open space occurred in recreation areas rather than conservation areas or other types of open space considered to have conservation value, such as cemeteries (Lussenhop, 1977; Smith & Minor, 2019). Conservation areas are likely a strong draw for people specifically looking to see birds, especially particular species that are uncommon in densely populated areas (Kolstoe & Cameron, 2017). In general, however, the relative accessibility of recreation areas may account for their higher usage for observing birds. In Chicago in particular, many recreation areas are located close to the downtown area and Lake Michigan (Fig. 1), accessible by public transportation, and frequented by tourists. Recreation areas also provide opportunities for people to observe birds casually while participating in other activities, such as meeting friends, visiting a tourist attraction (e.g., the 'bean' statue at Millennium Park), or attending a concert or other event. Incidental nature observations, such as hearing birdsong, can have positive effects on mental well-being (Bakolis et al., 2018; Keniger et al., 2013) and green infrastructure design can incorporate key elements to enhance these incidental interactions and associated benefits (Beery et al., 2017).

We found that fewer bird observations were recorded in lower-income community areas, perhaps because wealthier people have more leisure time and access to equipment for viewing and photographing birds, as well as technology for recording observations on online platforms. Different communities within a city may also engage differently with birds and with urban nature and green spaces more broadly. Indeed, several studies have pointed out that different urban populations often use parks differently (Lin, Fuller, Bush, Gaston, & Shanahan, 2014; Sasidharan, And, & Godbey, 2005) and that projects aimed at increasing open space in neighborhoods should thus consider how local communities use green space (Kabisch & Haase, 2014; Soga et al., 2015). Nevertheless, these results point to some potential opportunities for education and outreach to make people more aware of the biodiversity in their neighborhoods.

People's orientations towards or connection to nature is often an important factor influencing whether and how people use green space, whether they notice and appreciate biodiversity, and their participation in conservation behaviors (Gunnarsson, Knez, Hedblom, & Sang, 2017; Lin et al., 2014; Nisbet, Zelenski, & Murphy, 2009). Environmental education and outreach have the potential to enhance these qualities by increasing people's knowledge and appreciation of nature, including their ability to notice species they encounter (Cosquer et al., 2012; Pollock et al., 2015). This is especially true for those with limited prior exposure to nature (White, Eberstein, & Scott, 2018). Thus, targeting traditionally underserved areas for outreach efforts, as some programs in Chicago (e.g., Project Exploration, https://projectexploration.org/) are currently doing, could help to "close the gap" in bird observations we documented. As we found that people observe birds in various land uses across the city, there is clear potential for environmental education to take place in residential areas and other land uses (such as commercial areas) as well as open spaces. Citizen science projects, including those focused on residential areas such as backyard bird monitoring programs (e.g., Project Feederwatch, https://feederwatch.org/; Neighborhood Nestwatch, https://nationalzoo.si.edu/migratory-birds/about-neighborhood-nestwatch), can help to engage urban citizens with nature and potentially form stronger connections between people and their environment (Schuttler, Sorensen, Jordan, Cooper, & Shwartz, 2018). By offering a way to learn new species using only a smartphone, apps like iNaturalist can also be a useful tool for increasing engagement in observing birds and other organisms in various places throughout a city.

The data we used in this study capture only a subset of the possible interactions that people have with birds, and there are many reasons why an observation of a bird would not be recorded on an online platform. Indeed, some of the differences in patterns we observed between platforms most likely reflect differences in the types of information required for each platform; for example, the higher proportion of eBird observations we found on roadways is likely due in part to the fact that eBird, unlike the other platforms, does not require a photo. Our data as a whole are most likely biased against populations that do not have access to smartphones or personal computers (although 83% of urban residents have smart phones; Pew Research Center, 2018), those that are unaware of or uninterested in the particular online platforms we pulled data from, and those who observe birds but have never considered recording those observations in a public dataset. It is important to note that there are demographic biases in the users of various social media platforms, in terms of age, education, gender, and other factors (Smith & Anderson, 2018). Unfortunately, a common issue with online crowd-sourced data is a lack of information about the contributors that can be used to estimate these biases (Ruths & Pfeffer, 2014), and we are not aware of accessible user demographic data for the platforms we used in this study. We attempted to address this issue by including data from three different platforms, which appear to have somewhat different user groups with different motivations, as well as different specific requirements for recording observations.

Future studies could improve upon our methods by comparing the locations of bird observations recorded online to locations where people use social media sites (e.g., Flickr, Twitter) for other purposes, and locations where people use iNaturalist to observe organisms other than birds. This information on “observer bias” could provide a distinction between places where there are no bird observations because people are not observing birds versus where people are not recording observations online (Walker, Colton Flynn, Ovando-Montejo, Ellis, & Frazier, 2017). Future studies could also attempt to distinguish between local contributors and tourists, which could help to parse patterns of observations across land uses and neighborhoods. Finally, the platforms we used (namely Flickr and iNaturalist) could provide additional data on other types of urban human-nature interactions, such as observations of other types of wildlife besides birds. Although our study demonstrates some challenges associated with interpreting data from citizen science and social networking sites, it also highlights the potential for this type of data to provide insight into human-wildlife interactions, particularly in cities.

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Appendix A. . Comparison of data available from the three online platforms. This table shows examples of the types of data available from each of the three platforms, using edited examples. Each platform provides some kind of unique identifier for each observation, a user name or identification number, and the date, latitude, and longitude of the observation. We also used the “positional_accuracy”, “coordinates_obscured”, and “captive_cultivated” fields from iNaturalist data to filter out observations with inaccurate locations of captive or cultivated birds. We used the “LOCALITY TYPE” and “PROTOCOL TYPE” fields from eBird to select observations from known locations that were collected with the “incidental”, “stationary”, and “traveling” protocols. We used tags from Flickr images, along with the title of the photograph, to search for photographs of birds.

Platform	Unique identifier (URL)	User ID	Date	Latitude	Longitude	Common name	positional_accuracy	coordinates_obscured	captive_cultivated	LOCALITY TYPE	PROTOCOL TYPE	tags
iNaturalist	https://www.inaturalist.org/observations/1234567	birdguy	9/6/2017	41.9571205	-87.719572	American Redstart	30	FALSE	FALSE			
eBird	URN:CornellLabOfOrnithology:EBIRD:OBS123456789	obsr123456	9/10/2016	41.87103	-87.66052	Chimney Swift				H*	eBird - Incidental Observation	
Flickr	https://farm9.staticflickr.com/1234/12345678901_ab1c234de5_b.jpg	12345678@N01	5/22/2015	41.961532	-87.736816							yard catbird

* H = Hotspot

* H = Hotspot

Appendix B. . Categorization of land use types from the CMAP data.

Code	CMAP Category	CMAP Broad Category	Analysis Category
1111	Single-Family Detached	Residential	Single Family Residential
1112	Single-Family Attached	Residential	Single Family Residential
1130	Multi-Family	Residential	Multi-Family Residential
1140	Mobile Home Parks and Trailer Courts	Residential	Single Family Residential
1151	Common Open Space in a Residential Development	Residential	Other Open Space
1211	Shopping Malls	Commercial	Other
1212	Regional & Community Retail Centers	Commercial	Other
1214	Single Large-Site Retail	Commercial	Other
1215	Urban Mix	Commercial	Other
1216	Urban Mix w/Residential Component	Commercial	Other
1220	Office	Commercial	Other
1240	Cultural/Entertainment	Commercial	Other
1250	Hotel/Motel	Commercial	Other
1310	Medical Facilities	Institutional	Other
1321	K-12 Educational Facilities	Institutional	Other
1322	Post-Secondary Educational Facilities	Institutional	Other
1330	Government Administration and Services	Institutional	Other
1340	Prison and Correctional Facilities	Institutional	Other
1350	Religious Facilities	Institutional	Other
1360	Cemeteries	Institutional	Other Open Space
1370	Other Institutional	Institutional	Other
1380	National Laboratory	Institutional	Other
1410	Mineral Extraction	Industrial	Other
1420	General Industrial < 100,000 sq. ft.	Industrial	Other

1431	Manufacturing/Processing	Industrial	Other
1432	Warehousing/Distribution	Industrial	Other
1433	Flex or Indeterminate	Industrial	Other
1450	Storage	Industrial	Other
1511	Rail Right-of-Way	Trans/Comm/Util/Waste	Road/Right of Way
1512	Roadway	Trans/Comm/Util/Waste	Road/Right of Way
1520	Other Linear Transportation with Associated Facilities	Trans/Comm/Util/Waste	Other
1530	Aircraft Transportation	Trans/Comm/Util/Waste	Other
1540	Independent Automobile Parking	Trans/Comm/Util/Waste	Other
1550	Communication	Trans/Comm/Util/Waste	Other
1561	Utility Right-of-Way	Trans/Comm/Util/Waste	Road/Right of Way
1562	Wastewater Treatment Facility	Trans/Comm/Util/Waste	Other
1563	Landfill	Trans/Comm/Util/Waste	Other
1564	Other Utility/Waste	Trans/Comm/Util/Waste	Other
1565	Stormwater Management	Trans/Comm/Util/Waste	Other
1570	Intermodal Facility	Trans/Comm/Util/Waste	Other
2000	Agriculture	Agriculture	Other
3100	Open Space, Primarily Recreation	Open Space	Recreation Open Space
3200	Golf Course	Open Space	Recreation Open Space
3300	Open Space, Primarily Conservation	Open Space	Conservation Open Space
3400	Non-Public Open Space	Open Space	Other Open Space
3500	Trail or Greenway	Open Space	Other Open Space
4110	Vacant Residential Land	Vacant/Undeveloped Land	Other
4120	Vacant Commercial Land	Vacant/Undeveloped Land	Other
4130	Vacant Industrial Land	Vacant/Undeveloped Land	Other
4140	Other Vacant	Vacant/Undeveloped Land	Other
4210	Under Construction, Residential	Under Construction	Other
4220	Under Construction, Commercial	Under Construction	Other
4230	Under Construction, Industrial	Under Construction	Other
4240	Under Construction, Other or Unknown	Under Construction	Other
5000	Water	Water	Water
6100	Non-Parcel Open Space	Non-Parcel Areas	Other Open Space
6200	Non-Parcel Water	Non-Parcel Areas	Water
6300	Non-Parcel Right-of-Way	Non-Parcel Areas	Road/Right of Way
6400	Non-Parcel NEC	Non-Parcel Areas	Other
9999	Not Classifiable	Not Classifiable	Other

Appendix C. Results of pairwise Fisher's tests for individual land use types.

Table C1
Results of pairwise Fisher's tests comparing the proportions of observations found in different land uses to the proportional area in different land uses.

	Odds Ratio Observations:Area	p-value
Conservation Open Space	3.85393	< 0.001
Recreation Open Space	13.41377	< 0.001
Open Space (total)	11.73423	< 0.001
Water	2.533313	< 0.001
Roadways and Rights-of-way	0.4485004	< 0.001
Multi-Family Residential	0.2403651	< 0.001
Single Family Residential	0.05329882	< 0.001
Residential (total)	0.1001066	< 0.001
Other	0.6021355	< 0.001

Table C2
Results of pairwise Fisher's tests comparing the proportion of observations in different land uses between the three platforms.

	Odds Ratio eBird:iNaturalist	p-value	Odds Ratio iNaturalist:Flickr	p-value	Odds Ratio eBird:Flickr	p-value
Conservation Open Space	0.7752102	0.110	9.524158	< 0.001	7.395976	< 0.001
Recreation Open Space	0.8549556	0.108	0.8130295	0.103	0.6949954	< 0.001
Open Space (total)	0.8632902	0.130	1.098763	0.454	0.9486083	0.570
Water	1.4548	0.0426	0.3646597	< 0.001	0.5300731	< 0.001
Roadways and Rights-of-way	1.143673	0.381	1.415191	0.090	1.619019	< 0.001
Multi-Family Residential	0.4304519	< 0.001	1.345609	0.323	0.5793575	0.016
Single Family Residential	0.8591455	0.672	2.08581	0.362	1.793215	0.323
Residential (total)	0.5093887	< 0.001	1.462013	0.155	0.7449754	0.146
Other	1.189215	0.166	1.133804	0.463	1.348471	< 0.001

Appendix D. Comparison of simulated and observed number of bird observations across community areas.

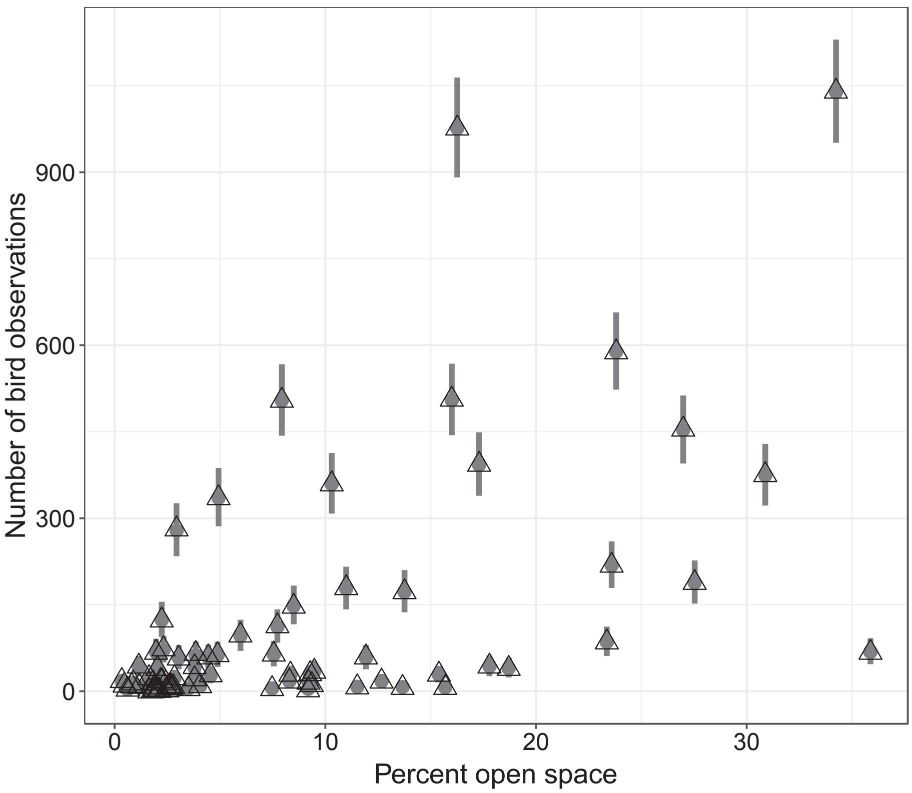

Fig. D1. Comparison of simulated and observed number of bird observations across community areas, in relation to the percent of open space area in community areas. Lines show credible intervals of simulated data from the Bayesian linear model, with points at the means. Observed data points are shown as open triangles. Observed points fall well within the range of predicted values, showing adequate model fit.

Appendix E. Comparison of land use distributions between observations filtered by location (one observation per person per location) and observations filtered by visit (one observation per person per location per day).

In this study, we filtered the raw data of bird observations to retain only one observation per individual per location, in order to identify land uses and neighborhoods where the most people recorded observations of birds online. To determine the effect of this filtering method on the results of the analyses, we re-ran the analyses on a dataset filtered to one observation per individual per location per day (i.e., one observation per daily visit to a location). Filtering by visit produced a larger dataset of observations, but the datasets for each platform were more strongly dominated by individual contributors who recorded bird observations at the same locations many times (Table E1).

Table E1
Number of observations and maximum number of observations made by a single individual on each platform in the unfiltered dataset, the dataset filtered by location (i.e., one observation per individual per location), and the dataset filtered by visit (i.e., one observation per individual per location per date).

	Unfiltered dataset	Filtered by location	Filtered by visit
Number of observations			
eBird	629,807	7944	33,696
iNaturalist	1307	474	801
Flickr	3981*	561	561
Total	635,095	8979	35,058
Maximum number of observations per individual			
eBird	31,076 (5%)	144 (2%)	2,271 (7%)
iNaturalist	404 (31%)	79 (17%)	287 (36%)
Flickr	997 (25%) *	45 (8%)	45 (8%)

* The unfiltered dataset for Flickr contained all images returned by a search for the term ‘bird’, which included collections of photos documenting the same subject (e.g., multiple shots of a single bird or flock), as well as photos that did not actually contain a bird. To remove duplicate observations, we filtered this dataset to one photo per individual user prior to examining photos manually to determine whether or not the subjects were indeed birds (Mancini, Coghill, & Lusseau, 2018a,b).
Therefore the ‘location’ and ‘visit’ filtering methods returned the same number of observations from Flickr.

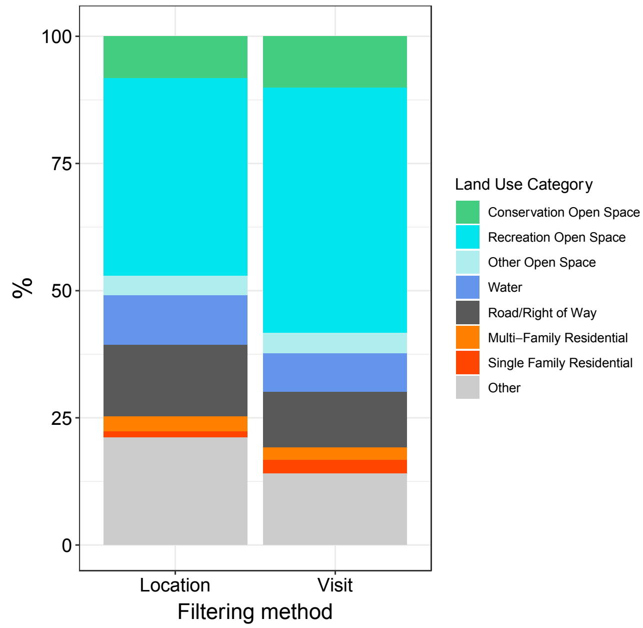

Fig. E1. Comparison of proportions of bird observations in different land uses between datasets filtered to one observation per individual per location ('Location') versus filtered to one observation per individual per location per date ('Visit'). Pairwise Fisher's exact tests showed significant differences between the two datasets in every land use type.

The different filtering methods produced different results when we compared the proportions of observations in different land uses, using Fisher's exact tests (Fig. 1). Compared to filtering observations to one individual per location, filtering to one observation per per daily visit to a location increased the proportion of observations recorded in conservation areas (odd ratio 1.25, $p < 0.001$), recreation areas (odds ratio 1.47, $p < 0.001$), and open space overall (odds ratio 1.60, $p < 0.001$); increased the proportion recorded in single-family residential areas (odds ratio 2.10, $p < 0.001$) and residential areas overall (odds ratio 1.23, $p < 0.001$), while decreasing the proportion found in multi-family residential areas (odds ratio 0.85, $p < 0.001$); and increased the proportion of observations recorded on water (odds ratio 0.74, $p < 0.001$) and roadways and rights-of-way (odds ratio 0.75, $p < 0.001$). The largest difference between the two filtering methods was in the proportion of observations recorded in recreation areas (39% in the location-filtered data and 48% in the visit-filtered data). There was no appreciable difference in the effect sizes of variables predicting the total number of bird observations in different community areas (Fig. 2).

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