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Does demolition improve biodiversity? Linking urban green space and socioeconomic characteristics to avian richness in a shrinking city

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Abstract Anthropogenic change, specifically urbanization, has lasting impacts on biodiversity and ecosystem services. Past work has linked green space variables and socioeconomic characteristics with biodiversity in urban areas. Shrinking cities present an interesting case for studying biodiversity because many of these places have implemented demolition policies to remove vacant buildings from the landscape, which returns previously urbanized land back into a "natural" state. The objective of this study is to investigate the multifaceted relationship among urban green space, socioeconomic characteristics, demolition activities, and avian species richness in the shrinking city of Buffalo, NY. We first establish a baseline understanding of how social and ecological factors are related to avian species richness through generalized linear models (GLM) and then incorporate a variable characterizing demolition to understand how the process of demolition may be impacting species richness relative to other factors. Second, since our analysis relies on "citizen science" data from eBird, we aim to better understand the factors driving eBird participation in Buffalo through zero-inflated negative binomial (ZINB) regression models to test how social and ecological characteristics and demolition affect checklists submission across the city. Our findings suggested that demolition activities do not increase species richness in Buffalo, indicating these sites may not be returning to a natural state that is usable by birds. We also found that areas that have undergone considerable demolition may be a potential deterrent to eBird participation, and eBird users may create bias by sampling areas with greater green space connectivity, and thus higher richness.

Keywords Biodiversity · Green space · Urban species richness · Zero-inflated models · Perforation · Urban decline

Introduction

Biodiversity is declining at an alarming rate worldwide (Erlich and Wilson 1991; Gaston 1995), and these declines have largely been attributed to a loss of habitat (Brooks et al. 2002). Specifically, land use/land cover change in the form of urbanization decreases the amount of habitat (Gaston et al. 2002), which has been found to have lasting impacts on biodiversity and ecosystem processes (Chapin et al. 1992; Tian et al. 2011; Caliman et al. 2013) by altering spatial patterns (Luck 2007). Additionally, these habitat decreases change the ecological integrity of a landscape (Rebele 1994) by modifying temperature (Baker et al. 2002; Arnfield 2003), precipitation (Shepherd 2005; Collier 2006; Hand and Shepherd 2009), and ultimately impacting ecosystem services (Tratalos et al. 2007; Eigenbrod et al. 2011; Cumming et al. 2014) such as nutrient cycling and climate regulation (Jenerette et al. 2007). Once these changes have occurred, they are often irreversible (Estoque and Murayama 2014), and it has proven difficult to retrofit habitat in the form of green spaces back into the city fabric once land has been developed (Jim and Chen 2003).

Adding complexity to the issue, the amount of green space is not always distributed evenly across cities. Specifically, studies have uncovered relationships between urban socioeconomic characteristics and the quality and quantity of green

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space (Redman et al. 2004). For example, Jenerette et al. (2011) found greater amounts of vegetation cover associated with higher income areas in Phoenix. Similarly, Iverson and Cook (2000), Troy et al. (2007), and Landry and Chakraborty (2009) found significantly lower tree cover in areas with higher proportions of minorities, low-income individuals, and renter-occupied units. These variations in the amount and structure of green space directly affect the quantity and quality of habitat for urban biodiversity. For example, studies have found park size to be the most important indicator of species richness, specifically for birds (Huang et al. 2015), and studies have found declines in bird biodiversity have lasting impacts across the entire ecosystem (Sekercioglu et al. 2002; Sol et al. 2014). Birds can be very sensitive to green space characteristics (Jokimaki and Kaisanlahti-Jokimaki 2003) such as habitat heterogeneity (Pellissier et al. 2012), connectivity (Rudd et al. 2002; Fernandez-Juricic 2000b), vegetation age (Fernandez-Juricic 2000a), vegetation complexity (Savard et al. 2000), patch size (Loss et al. 2009), disturbance (Battisti and Fanelli 2016), and edge effects (Fernandez-Juricic 2001). Thus, as the quantity and quality of available green space habitat for avian species varies across the city, so too will their abundance and richness.

Recognizing the relationships between socioeconomics and green space (Grove 1997; Grove et al. 2006) as well as the connections between green space and biodiversity, several studies have attempted to link socioeconomic characteristics directly with biodiversity, and there is evidence that both bird species richness (Melles 2005; Kinzig et al. 2005; Strohbach et al. 2009) and plant richness (Hope et al. 2003) increase along a socioeconomic gradient, with areas of higher income and education supporting more diversity. Davis et al. (2012) looked jointly at the distribution of bird diversity and green space across an urban gradient in Chicago and concluded that residents with higher socioeconomic status enjoyed more access to green space and experienced higher levels of avian species richness. These associations among socioeconomics, urban green space, and biodiversity (Li et al. 2015) highlight that biodiversity may not be distributed evenly for all residents of urbanized areas, which is cause for concern since many ecosystem service benefits are linked to biodiversity and natural environments (Costanza et al. 1997). Thus, it is useful to explore these relationships within a spatial social-ecological framework (Lerman and Warren 2011) that can incorporate all three factors.

Shrinking cities present a particularly interesting area in which to investigate these relationships because the land use/land cover changes taking place in these cities is quite different from the rapid population growth that characterizes most global cities. Shrinking cities are urban areas that have experienced a sustained decrease in population over time (Weaver et al. 2016), and they account for more than 25% of the world's largest cities (Rieniets 2006). Shrinkage typically results from a combination of deindustrialization, suburbanization, and demographic shifts (Hollander and Nemeth 2011; Hollander et al. 2009; Schilling and Mallach 2012; Wiechman and Pallagst 2012), although historically, reasons have also included disease, war, and other factors as well.

Shrinking cities present an interesting case for studying urban green space effects because many of these places have been implementing demolition policies to remove vacant and abandoned buildings from the landscape (Mallach 2011; Frazier et al. 2013; Weaver et al. 2016). The process of demolition converts developed land back into a natural or semi-natural state, thus creating the opportunity for retrofitting green spaces back into the urban form (Schetke and Haase 2008; Schilling and Logan 2008; Hollander et al. 2009; Frazier and Bagchi-Sen 2015) and potentially reversing habitat loss and increasing biodiversity. Several studies have suggested that demolition may have positive impacts on ecology (Haase 2008; Strauss and Biedermann 2006; Mathey et al. 2015) by providing ecosystem services through their conversion back to open space (Burkholder 2012). However, very few studies have tested these hypotheses empirically.

The objective of this study is to investigate the multifaceted relationships among urban green space, socioeconomic characteristics, demolition activities, and biodiversity (measured through avian species richness) in the shrinking city of Buffalo, NY. First, we assess the relationship between various social and ecological factors, including demolition activities, with avian species richness to determine the factors that contribute most to biodiversity across the city using generalized linear models (GLMs). Through this objective, we aim to better understand whether demolition of urban lots and their conversion back into a non-built up state is contributing to an increase or decrease in biodiversity. Specifically, we measure avian species richness via checklists submitted to eBird—a real-time, online platform for the public to document the presence, absence, and richness of species in their communities—and derive the explanatory power of various socio-ecological variables gathered via remote sensing and the U.S. Census Bureau on avian richness through the GLMs. Once we establish a baseline understanding of the social and ecological factors contributing to biodiversity across the city, we then include a measure of demolition to explore the relative impacts of these activities on biodiversity. Second, since participation in citizen science projects such as eBird is known to vary across geographical contexts (e.g., greater participation in parks versus certain neighborhoods) we also analyze the potential factors contributing to the likelihood of "citizen scientists" submitting eBird checklists in a shrinking city as well as the number of checklists submitted in each block group through zero-inflated binomial regression modeling. In sum, we attempt to better understand the relationship between demolition activities in a shrinking city and urban ecology since these areas may provide key ecosystem services.

Study area

The city of Buffalo, NY, located in Erie County, is an ideal location for this study due to the city's rich legacy of parks and green space along with its more recent history of population decline. The city has experienced steady population decline since the 1950s (Hollander and Cahill 2011), suffering many of the same crises as other Rust Belt cities including economic-infrastructure shifts, nationwide migration to sun-belt cities, suburbanization, racial segregation, and globalization (Frazier et al. 2013). As of 2010, decreasing population had produced a vacancy rate of 17.2%, manifesting in 25,000 vacant buildings across the city (U.S Census Bureau 2010). To combat the social and economic issues that arise from abandoned buildings (e.g., crime and other derelict activities), Buffalo implemented a demolition policy in 2007 known as the "5 in 5 Demolition Plan", which aimed to demolish 5000 structures over five years (DAFPU 2007). Although those targets were ultimately not met, the city did succeed in demolishing nearly 3000 properties during that time period (Frazier et al. 2013). The empty lots resulting from building demolition have the potential to increase green space for urban wildlife (Frazier and Bagchi-Sen 2015; Delmelle 2015) such as birds, but the actual impact of this newly available green space on avian species richness remains unknown.

Buffalo, is also exemplary for its network of public parks (Fig. 1), which were designed by Frederick Olmsted, credited as the father of American landscape architecture (Beveridge 2002). Olmstead's designs were greatly influenced by his childhood experiences in nature, and he thought parks should create a peaceful and soothing escape (Olmstead 1997). Olmstead sought to plan parks with the intention of making the parks not only a thing of beauty but also providing a service (Beveridge 2002). The park system Olmstead created in Buffalo consists of six major parks (Cazenovia, Delaware, Front, Martin Luther King Jr., Riverside, and South; Fig. 1a) as well as parkways connecting the major parks (Fig. 1c). These parks and parkways are credited with being the first planned municipal park system (Buffalo Olmsted Parks Conservancy 2016). The novel consideration of green space connectedness during Buffalo's early development in the 1900s coupled with its more recent issues planning for population loss and decline through demolition makes Buffalo an ideal place to investigate the relationship between natural and social characteristics on urban bird richness patterns.

Data and methods

To carry out our objectives, we constructed species richness models to understand the relationship among various social and ecological factors, including demolition, and biodiversity in a shrinking city. We first established a baseline understanding of how social and ecological factors are related to avian

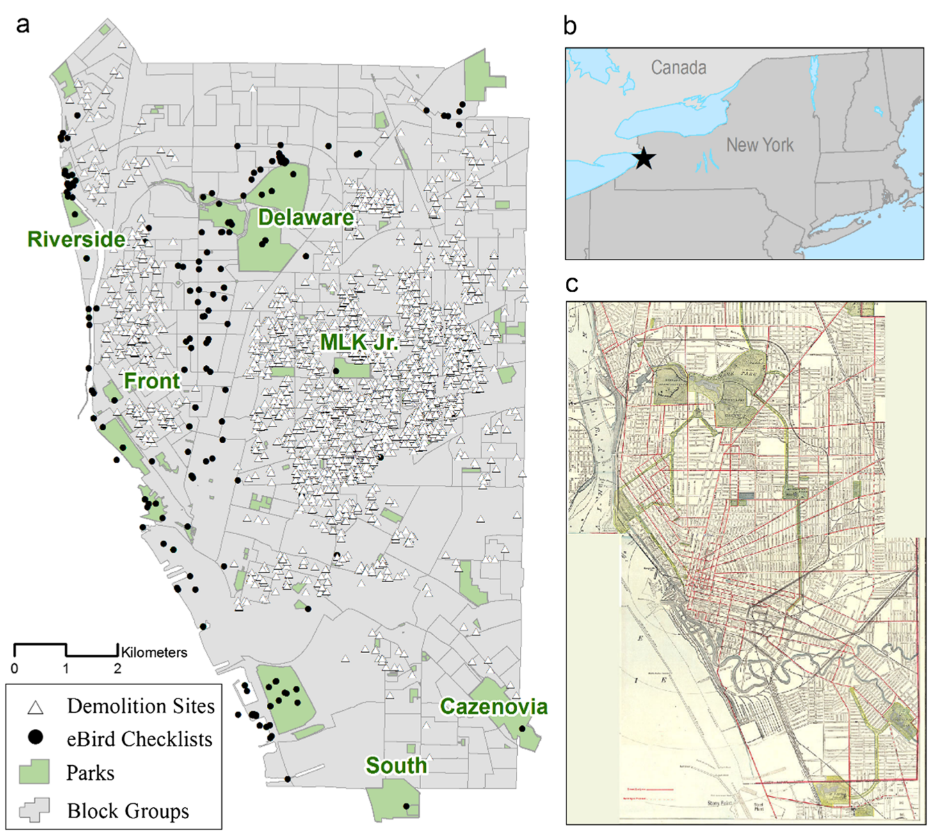

Fig. 1 **a** Buffalo block groups with locations of submitted eBird checklists; **b** regional location of the study area; **c** Historic map of Olmstead park system in Buffalo (Image: University at Buffalo Libraries)

species richness and then incorporated a variable characterizing demolition into our models to understand how the process of demolition may be impacting species richness relative to other variables in a shrinking city. Second, to better understand the factors driving eBird participation in Buffalo, we employed zero-inflated binomial regression models to test how social and ecological characteristics along with demolition activity may be affecting whether or not checklists are submitted in neighborhoods across the city. The data and methods are described in detail below. For all analyses, the geographic units of analysis are 2010 census block groups (U.S Census Bureau 2010).

Data

Avian species richness

We acquired avian species richness data from eBird, a citizen science project launched in 2002 by the Cornell Lab of Ornithology (Sullivan et al. 2009). Volunteers can submit bird sightings through eBird to an online archive where data can then be requested by researchers. In 2013, eBird had 150,000 users and over 140 million submitted observations (Sullivan et al. 2014). Citizen science data, such as eBird checklists, have been found to sometimes contain biases such as variation among and within observers (Cooper et al. 2007; Kelling et al. 2015), false negatives or under-reporting (McClintock et al. 2010), and, particularly relevant in our case, the uneven distribution of data collection (Boakes et al. 2010). Boakes et al. (2010) found that occurrence records submitted by users to web-based platforms such as eBird may be biased according to population density, places observers visit often (e.g., parks), and the level of scientific knowledge (e.g., education) of the participant. Checklists submitted for Buffalo suggest geographical bias, as the spatial distribution varies across the city, and most census block groups have not been sampled (see Fig. 1a). Despite these known biases, Callaghan and Gawlik (2015) investigated the robustness of eBird data compared to professional bird surveys and found no significant difference between diversity metrics calculated from eBird compared to professional surveys. Additionally, their research concluded that eBird data can be applied to smaller-scale research designs (Callaghan and Gawlik 2015). Therefore, eBird is an appropriate platform from which to investigate avian species richness in a mid-sized city such as Buffalo, NY.

We acquired all eBird observation checklists (eBird Basic Dataset 2015) submitted in Erie County, NY, in 2012 (to match our green space, socio-economic, and demolition variables discussed below) and filtered observations to the city of Buffalo. We then calculated the total number of checklists submitted for each block group as well as the total number of species observed from all submitted checklists. Because species richness in an area can change temporally throughout the year due to breeding season behavior (i.e., territoriality) and migration, we calculated total species richness according to total counts from the checklists in order to account for the temporal use of space by birds.

Green space variables

To relate avian species richness to the ecological characteristics in each block group, we derived four green space variables from a high-resolution World View-2 (WV2) image (Digital Globe, Inc.). The four variables are: proportion of green space/proportion of urban area, mean area of green space patches, cohesion of green space patches, and average Normalized Difference Vegetation Index (NDVI) in each block group. The WV2 image was acquired on 25 July 2012, coinciding with peak vegetation greenness in the city of Buffalo. WV2 collects data in four multispectral bands (blue, green, red, and near infrared [NIR]) at a spatial resolution of 1.85 m. We radiometrically and atmospherically corrected the image using ENVI's Quick Atmospheric Correction (QuAC) module (Bernstein et al. 2012) and then performed a Maximum Likelihood Classification (MLC) to classify the image into three land cover classes. MLC is the most common supervised classification technique for remotely sensed data (Richards and Jia 1999) and has been found to be the most robust when the spectral information is normally distributed (Bischof et al. 1992). We collected training samples for three classes: green space (all vegetation), impervious surface/urban, and water, and then tested the classification accuracy using ground reference information. We did not differentiate between grassy areas and trees in our green vegetation class, as studies have found that inner-city grassy sites can constitute niches in which rare species may thrive (Strauss and Biedermann 2006). Overall, classification accuracy for the entire image was high (91.2%), and individual class accuracies were also high, particularly for green space (producer's accuracy =98.3%, user's accuracy =98.3%), with impervious surface/urban also well within accepted limits (producer's accuracy =97.1%, user's accuracy =84.8%). Using these classification results, we computed the proportion of each block group classified as green space and impervious surface/urban. Since these two variables are highly correlated with each other in urban areas, we elected to include only the proportion of impervious surface/urban land cover in our models (discussed below). Hereafter, we refer to this variable as proportion of urban land.

In addition to the proportion of green space in an urban area, the configuration of that greenspace in terms of patch size and connectivity are important for urban wildlife (Fernandez-Juricic 2000a; Kang et al. 2015). We calculated mean area of green space patches within each block group using ArcMap (ESRI 2014). To avoid duplication from patches straddling block group boundaries, we employed a spatial union based on the patch centroid to extract green space patches to a single block group only. We also computed a measure of connectivity to characterize green space structure. Because species exhibit differing dispersal abilities, functional connectivity of habitat patches varies from species to species (LaPoint et al. 2015). Therefore, we elected to compute structural connectivity via the patch cohesion metric for each block group using Fragstats (McGarigal et al. 2012). Cohesion quantifies the physical connectedness of patches within a class (i.e., green space) using the following equation:

$$COHESION = \left[1-\frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1-\frac{1}{\sqrt{A}}\right]^{-1}(100)$$

where p_{ij} is the perimeter of a patch, a_{ij} is the area of the same patch, and A is the total number of pixels in the landscape (McGarigal et al. 2012). To fully account for the connectivity of urban green space patches that extended beyond block group boundaries, overlapping patches were not clipped to block group boundaries and were allowed to contribute to connectivity in both block groups.

The level of vegetation greenness has also been found to correlate with biodiversity (Gould 2000), so we computed NDVI, which measures vegetation greenness as a proxy for vegetation biomass and/or health (Rouse et al. 1974) using reflectance from wavebands involved in chlorophyll production (Jones and Vaughan 2010). We calculated NDVI for each pixel using the following equation:

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)}$$

where *Red* represents the spectral reflectance in the visible red region and *NIR* represents the reflectance from the near infrared region. Resulting NDVI values range from −1 to 1, with 1 indicating the surface is completely vegetated and values near −1 indicating an absence of green vegetation. We aggregated NDVI values from each pixel to the block group as an overall measure of greenspace health and vigor.

Socioeconomic variables

We selected five variables from the U.S. Census 2013 American Community Survey (ACS) to characterize socioeconomic conditions at the block group level to explore the linakges between urban biodiversity and social-ecological conditions as well as explore the factors driving eBird participation in Buffalo. The five variables include: population density, median income, median home price, proportion of renters, and proportion with college education. These variables are frequently used to explore linkages among species richness and green space quality and quantity (Kinzig et al. 2005; Strohbach et al. 2009; Li and Weng 2007; Ogneva-Himmelberger et al. 2013; Li et al. 2015; Melles 2005; Landry and Chakraborty 2009). All variables were aggregated to the block group level (Fig. 2). There are clear spatial patterns associated with population distribution, median income, and median home price (Fig. 2a–c) whereas the maps depicting proportion of renter occupied and the proportion of college educated do not show a strong spatial trend.

Demolition variable

To quantify the demolition activity occurring in each block group, we obtained a list of all government-initiated residential demolitions occurring between 2007 and 2012 (matching the "5 in 5 Demolition Plan" period) from the city of Buffalo. Demolitions carried out by homeowners for renovations, improvements, or rebuilding were not included, as they represent urban renewal, not necessarily shrinkage. We geocoded each demolition address to the Erie County land parcel GIS shapefile using ArcGIS. We then aggregated the total number of demolitions occurring in each block group for input into the models.

Investigating influence of demolition on avian richness

To investigate the multifaceted relationship among greenspace, socioeconomic characteristics, demolition activities, and biodiversity in Buffalo, we computed a variety of generalized linear models (GLMs) with various combinations of variables. Utilizing only block groups with species richness counts from eBird submissions (Fig. 1a), we computed nine GLMs to predict avian species richness, which included various combinations of the socioeconomic and green space variables previously described. Our models consisted of (1) a null

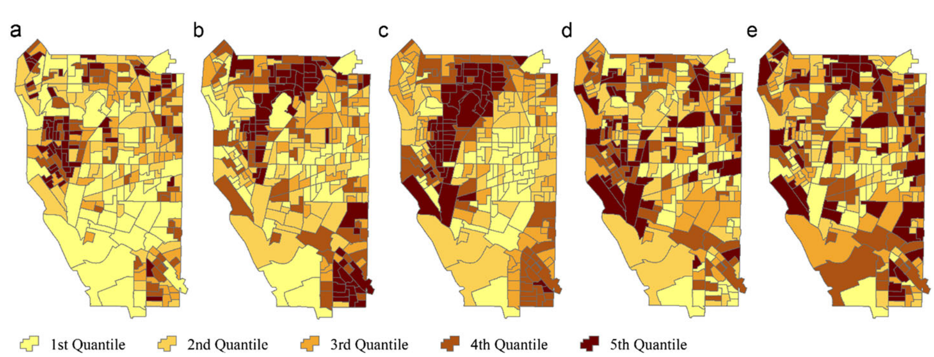

Fig. 2 Socioeconomic variables used in the analyses: **a** population density, **b** median income, **c** median home price, **d** proportion renter occupied, **e** proportion college educated

model that contained no variables, and (2) a full model including all nine socioeconomic and green space variables. We then computed (3) a green space model that encompassed all four green space variables, and (4) a socioeconomic variable that incorporated the five socioeconomic variables to test if solely green space or socioeconomic characteristics can best describe avian species richness in Buffalo. We also computed an additional five models to investigate the influence of (5) green space quality (using mean NDVI and connectivity), (6) green space quantity (using mean patch size and the proportion of urban land), (7) population size (using just population density), (8) social status (percent college educated and median income), and (9) neighborhood characteristics (median home price and proportion of renters) as drivers of bird diversity. We based our models on conclusions from published studies, which linked diversity metrics to aspects of urban green space and socioeconomic status Fernandez-Juricic 2000a; Savard et al. 2000; Rudd et al. 2002; Jokimaki and Kaisanlahti-Jokimaki 2003; Melles 2005; Kinzig et al. 2005; Loss et al. 2009; Strohbach et al. 2009; Lerman and Warren 2011; Davis et al. 2012; Pellissier et al. 2012; Huang et al. 2015; Li et al. 2015).

After establishing a baseline understanding of the social and ecological factors explaining biodiversity across the city through the above GLMs, we constructed an additional eight GLMs identical to the models described above (excluding the null model) that also included the demolition parameter (a count of the number of housing units demolished in each block group between 2007 and 2012). Frazier and Bagchi-Sen (2015) demonstrated that small patches of demolished structures can considerably increase the connectedness of green space across Buffalo, and from this we surmise that including a demolition parameter may increase model fit of species richness models.

We evaluated model performance using Akaike's Information Criterion (AIC), which estimates the relative Kullback-Leiber distance (difference between the true probability distribution and the distribution predicted by the model) (Burnham et al. 2011). AIC ranks models higher (more favorably) when this distance is lower and the number of parameters is lower, thus describing a more parsimonious model (Burnham and Anderson 2001). To rank the 16 models, we computed the delta AIC (ΔAIC) and AIC weights (AICω) from the calculated AIC values. Models with the lowest AIC and highest AICω were considered the best models for describing bird species richness, but all models with ΔAIC <2 were considered competing models (Anderson 2001). By using AIC to compare models, we were able to determine if the addition of the demolition parameter increased model explanatory power. The addition of a demolition parameter to each model increased model complexity, which AIC penalizes, unless the additional parameters better predict the true probability distribution. Thus, complex models can be ranked higher than more simple models, which we expected to be the case if the addition of demolitions better explained species richness patterns. Again, we considered models with the lowest AIC and highest AICω as the best models, and models with ΔAIC <2 as competing models.

Investigating eBird participation bias

Since there can be geographical bias associated with avian diversity reporting in eBird (see Fig. 1a), we employed a zero-inflated negative binomial (ZINB) regression model to account for the variables that may be contributing to the probability of a checklist being submitted to eBird as well as the number of checklists submitted in each block group (Sileshi 2008). For example, areas with higher green space amounts and connectivity may naturally attract bird enthusiasts, thus resulting in a greater probability of submission and a greater number of checklists submitted. ZINB models assume a logistic distribution to describe whether or not checklists were submitted and a negative binomial distribution to account for the number of checklists submitted. Negative binomial distributions are often used in ecology when observations are overdispersed (clumped) and Poisson distribution is not appropriate (Hilborn and Mangel 1997). We used various combinations of the socioeconomic, green space, and demolition characteristics to describe the number of eBird checklists ("count" component of model) and account for the probability of checklist submission ("logistic" component of model).

We tested 24 models with different combinations of parameters to describe the number and probability of checklist submission at the block group level based on several studies (McFarlane and Boxall 1997; Dallimer et al. 2012). The 24 models included a null model containing no parameters (just checklists) for both components and an additional 23 models using various combinations of the green space, socioeconomic, and demolition variables as potential explanatory variables in both the probability (logistic) and count (negative binomial) components of the model. Some models used the same variables to describe checklist probability and count, whereas others used different subsets for each component. Subsets of variables included in the count and logistic components of the ZINB modeling were those that described green space quality (mean NDVI and connectivity), green space quantity (mean patch area and proportion urban), education and income (proportion with college and median income), neighborhood characteristics (median home price and proportion of renters), and lastly population size (population density). All models were run in R (R Core Team 2015) using the packages bbmle (Bolker 2014), AER (Kleiber and Zeileis 2008), pscl (Jackson 2015), and lmtest (Zeileis and Hothorn 2002). As stated previously, we evaluated model performance using AIC and ranked the 24 models, with ΔAIC and AICω from the calculated AIC values. Again we considered competing models as those with ΔAIC <2 (Anderson 2001).

Results

Avian species richness results

From the 988 checklists submitted to eBird in 2012 for Buffalo, 241 different avian species were reported across the entire city. The most commonly reported bird was the Ring-billed Gull (*Larus delawarensis*; 482 observations), followed by Canada Goose (*Branta canadensis*; 476), Mallard (*Anas platyrhynchos*; 463), American Crow (*Corvus brachyrhynchos*; 434), and Black-capped Chickadee (*Poecile atricapillus*; 364). The number of species reported in each block group ranged from 1 to 188 species, with a median of 8 species per reported block group. The block group with 188 different species reported comprises the Tift Nature Preserve, which ironically is not one of Olmstead's original six anchor parks but instead was a municipal dumpsite until it was converted into a nature preserve in the 1970s. Located in the southwestern area of the city (Fig. 1a), the preserve currently includes over 102 ha of green space, making it one of the larger green spaces in the city, thus supporting the finding by Huang et al. (2015) that park size is an important factor in species richness.

The GLM modeling produced four competitive models for predicting avian species richness from greenspace, socioeconomic, and demolition variables (Table 1). The top three models ("full", "grnspc", and "full.demo") had ΔAIC values <2, indicating similar support. The "full" model (ΔAIC =0) included nine variables (four green space and five socioeconomic variables) whereas the "grnspc" model (ΔAIC =1.7) included only the four green space parameters. The third and fourth models included the demolition variable ("full.demo" and "grnspc.demo"). Since all four models are considered to be "competing" models, it cannot be concluded that any one outperformed the others. However, the increased complexity of the full model as well as its high ranking also hints at the possibility that green space alone may not be able to fully quantify diversity patterns across shrinking cities. Interestingly, the inclusion of the demolition variable decreased the prediction power of the "full" and "grnspc" models but not enough to lower their prediction power compared to all other models.

For all four models, green space connectivity (cn), proportion of urban land (pu), and the proportion of college educated (pc) were all significant variables for describing the avian species richness patterns. Green space connectivity was found to correspond to a significant increase in species richness, whereas increasing urban land cover corresponded to a decrease in species richness. These results support other studies

Table 1 Species richness generalized linear models (GLM) ranked by AIC

Model	Variables	AIC	dAIC	ωAIC
full	**pu**$^{-}$+mn + ma + **cn**$^{+}$+pd. + mi + mp + **pc**$^{-}$+pr	388.4	0	0.4907
grnspc	**pu**$^{-}$+mn + ma + **cn**$^{+}$	390.1	1.7	0.2107
full.demo	**pu**$^{-}$+mn + ma + **cn**$^{+}$+pd. + mi + mp + **pc**$^{-}$+pr + dm	390.2	1.8	0.1984
grnspc.demo	**pu**$^{-}$+mn + ma + **cn**$^{+}$dm	392.1	3.7	0.0783
quant	**pu**$^{-}$+ma	395.9	7.5	0.0113
qual	mn + **cn**$^{+}$	397.7	9.3	0.0047
quant.demo	**pu**$^{-}$+ma + dm	397.9	9.5	0.0042
qual.demo	mn + **cn**$^{+}$+dm	399.7	11.3	0.0017
		411.1	22.8	< 0.001
home	pr + mp	412.8	24.4	< 0.001
popden	pd	413.1	24.7	< 0.001
income	mi + pc	413.3	24.9	< 0.001
home.demo	pr + mp + dm	414.3	25.9	< 0.001
socecn	pd + mi + mp + pc + **pr**$^{+}$	414.4	26.0	< 0.001
popden.demo	pd + dm	414.7	26.3	< 0.001
income.demo	mi + pc + dm	415.1	26.7	< 0.001
socecn.demo	pd + mi + mp + pc + **pr**$^{+}$+dm	415.6	27.2	< 0.001

Model names are based on the selection of variables used where the first name corresponds to the count component and the second to the logistic portion: grnspc (all green space), socecn (all socioeconomic), home (housing conditions), income (socioeconomic status), density (population density), qual (green space quality), quant (green space quantity), and null (no variables). The ".demo" term refers to the addition of the demolition variable to the base model. Variables are: pu (proportion of urban land cover), mn (mean NDVI), ma (mean area), cn (connectivity), pd. (population density), mi (median income), mp (mean home price), pc (proportion of population with college degree), pr (proportion of population renting), and dm (number of sites demolished between 2007 and 2012). Bold variables are those that show statistical significance ($p < 0.05$), and superscript sign ($^{+}$ or $^{-}$) indicates direction of influence that have also found correlations between green space connectivity and urban land with biodiversity (Blair 1996; Rudd et al. 2002; Fernandez-Juricic 2000a). Interestingly, an increase in the proportion of college educated residents corresponded to a significant decrease in species richness across Buffalo. Since many of the Buffalo parks comprise entire block groups (or major proportions thereof) they may not have large resident populations and therefore may have low census counts for variables such as the number of college educated residents. These results suggest that eBird checklists are likely being submitted for block groups that may not correspond to the submitter's home block group.

Demolition showed a negative, albeit non-significant, relationship with species richness. There are several possible explanations for this finding. First, studies on urban shrinkage have suggested that demolition sites rarely return to a natural state (Haase 2008) but instead remain wastelands. Since the regeneration of demolition sites determines the quantity and quality of habitat available for species to use (Witting 2010), it is possible that these sites are not regenerating in a manner to provide suitable habitat for species and may not be contributing to green space connectivity, which we found to be a significant factor for avian species richness. It is also possible there is a temporal lag between demolition and regeneration of the site to vegetated habitat useful for birds that was not captured by our study. A second possible reason for the negative relationship between demolition lots and avian species richness is because eBird checklist submission may not coincide with the block groups experiencing the highest levels of demolition activity (Fig. 1a). These observations suggest two implications for biodiversity (and citizen science participation) in shrinking cities. First, Frazier and Bagchi-Sen (2015) found that the area of the most intense demolition activities had relatively less green space compared to the rest of the city. Thus, even a potential increase in green space from demolition may not affect biodiversity. Second, there may be participation biases associated with volunteers submitting checklists in Buffalo, NY, whereby eBird checklists are not being submitted in areas with high demolition activity. We explore this implication through the results of the ZINB modeling analysis discussed below.

Participation bias results

Of the 287 block groups in Buffalo, eBird checklists were submitted in 2012 for 50 block groups, or approximately 17%. The number of checklists submitted in each block group ranged from 1 to 230, with an average of 19.9 checklists submitted per block group. Checklists were not evenly dispersed across the city (Fig. 1a), as most block groups with checklists were located along Lake Erie or along the park network (Fig. 1c). The ZINB regression models allow a determination of factors that may be influencing participation. AIC values across the 24 models (Table 2) showed that there were only two competing models with ΔAIC values <2: grnspc(d).grnspc(d) and grnspc.grnspc. The first model name indicates the set of variables for the count portion of the model to predict the number of checklists submitted in each county, and the second name indicates the set of variables for the logistic portion of the model, which predicts the probability of a checklist being submitted. In this case, the two competing models both included only green space variables, with the first set also including the demolition variable (the "(d)" term).

As with the species richness models, the top two models again show that green space connectivity (cn) and proportion of urban land (pu) significantly explain the variation in submitted checklists. Increasing green space connectivity increased the number of number of submitted checklists whereas larger amounts of urban land cover were expected to decrease checklist number. Additionally, for the grnspc(d).grnspc(d) model, the demolition variable was associated with a significant decrease in the number of checklists. These findings corroborate our above results suggesting that demolition activity was a deterrent for checklist submission. In Buffalo, green space characteristics were able to explain eBird checklist submission to a greater extent than were socioeconomic characteristics. Some may find these results surprising since citizen science projects rely on volunteers to collect data, and socioeconomics are thought to play a large role in determining participation (Evans et al. 2005). However, our findings support other studies that have noted that participants in bird-related citizen science projects prefer areas of high biodiversity (Boakes et al. 2016), which in Buffalo corresponded to areas with high green space connectivity. While it appears that eBird users may be creating bias by sampling more densely areas with high richness, the problem is exacerbated by a handful of observers submitting large portions of the data from their favored observing locations, creating recording hotspots (Boakes et al. 2016). We see evidence of this in the mapped checklist locations as a majority of these are located by Lake Erie, presumably to sample the water bird population, and the Olmstead corridor, which connects the cluster of larger parks in the north to parks in the west. Our results suggest that at local scales, citizen science data may not be enough to examine diversity trends across urban landscapes, and a more systematic sampling technique may be needed. We do not mean to infer that citizen science data sets such as eBird are not useful; rather we feel that the accuracy of the data makes it more appropriate for either coarse scale analysis or for exploratory analysis such as our interest in demolition efforts on bird richness.

Conclusions

We investigated the relationships among urban green space, socioeconomic characteristics, demolition activities, and

Table 2 Checklist negative binomial zero-inflated (ZINB) models ranked by AIC

Model	Count Variables	Logistic Variables	AIC	dAIC	wAIC
grnspc(d).grnspc(d)	**pu**$^-$+mn + ma + **cn**$^+$+ **dm**$^-$	pu + mn + ma + **cn**$^-$+dm	551.6	0.0	0.5699
grnspc.grnspc	**pu**$^-$+mn + ma + **cn**$^+$	pu + mn + ma + **cn**$^-$	552.2	0.7	0.4107
grnspc(d).socecn	**pu**$^-$+mn + **ma**$^-$+ **cn**$^+$+dm	pd + **mi**$^+$+**mp**$^-$+**pc**$^+$+pr	559.2	7.7	0.0123
grnspc.socecn	**pu**$^-$+**mn**$^+$+**ma**$^-$+**cn**$^+$	pd + mi + mp + pc + pr	560.4	8.9	0.0067
socecn.grnspc	pd + mi + mp + **pc**$^-$+**pr**$^+$	pu + **mn**$^-$+ma + **cn**$^-$	566.7	15.1	< 0.001
socecn.grnspc(d)	pd + mi + mp + **pc**$^-$+**pr**$^+$	**pu**$^+$+mn + ma + **cn**$^-$+dm	568.9	17.3	< 0.001
qual.demo	**mn**$^+$+**cn**$^+$	dm	573.2	21.6	< 0.001
home.qual	**pr**$^+$+mp	**mn**$^-$+ **cn**$^-$	574.4	22.8	< 0.001
qual.income	**mn**$^+$+**cn**$^+$	mi + pc	575.7	24.1	< 0.001
qual.density	**mn**$^+$+**cn**$^+$	pd	576.2	24.6	< 0.001
demo.qual	dm	**mn**$^-$+ **cn**$^-$	578.9	27.3	< 0.001
density.qual	pd	**mn**$^-$+ **cn**$^-$	579.2	27.7	< 0.001
income.qual	mi + pc	**mn**$^-$+ **cn**$^-$	580.4	28.8	< 0.001
quant.demo	ma + **pu**$^-$	dm	588.8	37.3	< 0.001
quant.income	ma + **pu**$^-$	mi + **pc**$^-$	598.1	40.3	< 0.001
quant.density	ma + **pu**$^-$	pd	593.2	41.6	< 0.001
home.quant	**pr**$^+$+mp	ma + **pu**$^+$	596.4	44.6	< 0.001
demo.quant	dm	ma + **pu**$^+$	598.1	46.5	< 0.001
income.quant	mi + pc	ma + **pu**$^+$	600.7	49.2	< 0.001
null.null			613.4	61.8	< 0.001
density.quant	pd	ma + **pu**$^+$	619.4	67.8	< 0.001
socecn(d).socecn(d)	pd + mi + mp + **pc**$^-$+ pr + dm	pd + mi + mp + **pc**$^-$+ pr + dm	620.7	69.2	< 0.001
qual.home	mn + **cn**$^+$	pr + mp	2262.1	1710.5	< 0.001
quant.home	**ma**$^-$+ **pu**$^-$	pr + mp	2383.8	1832.2	< 0.001

Model names are based on the selection of variables used where the first name corresponds to the count component and the second to the logistic portion: grnspc (all green space), socecn (all socioeconomic), home (housing conditions), income (socioeconomic status), density (population density), qual (green space quality), quant (green space quantity), and null (no variables). The (d) indicates a model that includes the demolition variable, whereas.demo indicates a model component that utilizes the demolition variable only. Variables are: pu (proportion of urban land cover), mn (mean ndvi), ma (mean area), cn (connectivity), pd. (population density), mi (median income), mp (mean home price), pc (proportion of population with college degree), pr (proportion of population renting), and dm (number of sites demolished between 2007 and 2012). Bold variables are those that show statistical significance ($p < 0.05$), and superscript sign ($^+$ or $^-$) indicates direction of influence

biodiversity (measured through avian species richness) in a shrinking city to empirically test whether demolition activities are affecting biodiversity. We found that green space connectivity, proportion of urban land, and the proportion of college educated residents were all significant variables for describing the avian species richness patterns. The addition of demolition counts to the models showed that demolition has a negative relationship with species richness, suggesting that demolition lots may not be contributing to biodiversity in Buffalo, NY, according to eBird checklists. Possible explanations for this relationship include the lack of regeneration of demolition sites into viable habitat for birds and a possible temporal lag between demolition activities and site regeneration that we were not able to capture with our data. These findings may have also indicated an eBird sampling bias; we investigated the possible factors impacting eBird participation through zero-inflated negative binomial regression models. We found that green space connectivity and proportion of land cover type were also significant factors for describing the probability of having a checklist submitted in a particular block group as well as the number of checklists submitted. Our findings indicated that demolition was a deterrent for submitting eBird checklists in the city of Buffalo, suggesting that eBird users may not be sampling areas with high richness. Future research should explore whether there is indeed a temporal lag between demolition activities and regeneration of sites into “natural” habitat that is able to contribute to biodiversity.

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