Chapter 2
Global Patterns and Drivers of Urban Bird Diversity

Christopher A. Lepczyk, Frank A. La Sorte, Myla F.J. Aronson, Mark A. Goddard, Ian MacGregor-Fors, Charles H. Nilon, and Paige S. Warren

Abstract The rapid urbanization of the world has profound effects on global biodiversity, and urbanization has been counted among the processes contributing to the homogenization of the world's biota. However, there are few generalities of the patterns and drivers of urban birds and even fewer global comparative studies. Comparable methodologies and datasets are needed to understand, preserve, and monitor biodiversity in cities. We explore the current state of the science in terms of basic patterns of urban birds in the world's cities and lay out a research agenda to improve basic understanding of patterns and processes and to better inform conservation efforts. Urban avifaunas are often portrayed as being species poor and dominated by omnivorous and granivorous species that tend to be nonnative. Common families in cities include Accipitridae, Anatidae, and Scolopacidae, all

C.A. Lepczyk (✉)
School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA
e-mail: lepczyk@auburn.edu

F.A. La Sorte
Cornell Lab of Ornithology, Cornell University, Ithaca, NY 14850, USA

M.F.J. Aronson
Department of Ecology, Evolution, and Natural Resources, Rutgers, The State University of New Jersey, New Brunswick, NJ 08901, USA

M.A. Goddard
School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne NE1 7RU, UK

I. MacGregor-Fors
Red de Ambiente y Sustentabilidad, Instituto de Ecología, A.C., Carreteraantigua a Coatepec 351, El Haya, Xalapa, 91070 Veracruz, México

C.H. Nilon
School of Natural Resources, University of Missouri, 302 Anheuser-Busch Natural Resources Building, Columbia, MO 65211-7240, USA

P.S. Warren
Department of Environmental Conservation, University of Massachusetts at Amherst, 160 Holdsworth Way, Amherst, MA 01003, USA

E. Murgui, M. Hedblom (eds.), *Ecology and Conservation of Birds in Urban Environments*, DOI 10.1007/978-3-319-43314-1_2

of which have more species than expected in cities compared to the global distribution of species in these families. Recent research shows that cities support an avifauna dominated by native species and that cities are not homogenized at the global level. However, cities have lost substantial biodiversity compared to predicted peri-urban diversity, and 31 of the world's most invasive bird species are found in cities. Future research is needed to better characterize the anthropogenic, environmental, and ecological drivers of birds in cities. Such mechanistic understanding is the underpinning of effective conservation strategies in a human dominated world.

Keywords Homogenization • Invasive species • Land cover • Species traits

2.1 Introduction

The world of the twenty-first century is an urban one, with the majority of people now settled in some type of city, town, or other urban areas. At present 0.5–3.0 % of the globe's terrestrial land surface is in some form of urban land cover (see Liu et al. 2014 for discussion), and urban land cover is expected to continue growing concomitant with the human population over the twenty-first century (Seto et al. 2012). The rise in urban areas ultimately translates to habitat alteration, fragmentation, and loss for many species of flora and fauna. Because of urbanization's effects on habitat and species, it is often assumed that such wholesale transformation of the land has resulted only in ecological outcomes that might be considered detrimental, such as homogenization of species among cities (McKinney 2006). However, comparable data on species are needed across the urban areas of the world in order to assess what processes are leading to the patterns we observe and if there are commonalities among them.

Birds offer an ideal taxonomic group from which to understand the effects of urbanization on species using comparative approaches as more than 2,000 species (of the approximately 10,000 described species of birds globally) occur in urban areas (Aronson et al. 2014). Beyond the sheer number of species observed in urban areas, birds are well studied, easily observable, and important for the ecosystem services they provide. Additionally, birds can act as indicator species of habitats that support numerous other taxa. Hence, using birds as model taxa, we consider both what is currently understood about birds in cities and what are the next steps needed for both research and conservation.

Urban areas worldwide contain similar physical features and environmental conditions, and urban areas act as a focal point for the introduction of nonnative species and the extinction of native species (Sol et al. 2016; Tomiałojć 2016). As such, urban areas offer a unique opportunity to investigate the ecological consequences, as they develop globally, of intensive land-use change and human-mediated biotic interchange. Birds have played an important role advancing this global perspective, primarily through the prevalence of data on urban bird communities. Avian communities in North America and European cities are currently the best sampled and studied. However, efforts are increasingly being directed to developing data resources for cities outside these regions.

2.2 The Types of Birds Found in Cities

Geographically, cities form complex systems that differ markedly from those systems present before the urbanizing process began (Berkowitz et al. 2003; McKinney 2006). Such changes can present an ecological barrier for some animal species who are unable to traverse an urban area or utilize it, whereas other species are able to use some urban resources, and a few are highly successful at exploiting urban resources and conditions (Croci et al. 2008; MacGregor-Fors et al. 2010; Puga-Caballero et al. 2014). Because animals respond differentially to urbanization, they are often classified into the following categories: (1) *urban avoiders*, which are species that are generally absent in highly developed areas, but can be present in natural areas embedded in urban area; (2) *urban utilizers*, which are species that use urban resources and conditions but whose populations require immigration from natural areas; and (3) *urban dwellers*, which are species that reproduce and persist in urban areas (Fischer et al. 2015).

The presence and distribution of bird species inside a city depend, among other factors, on the biogeographic species pools, the natural history of species, and the nature and distribution of habitat-related traits (Lepczyk et al. 2008; MacGregor-Fors and Scondube 2011; McCaffrey et al. 2012). In general, omnivorous, granivorous, and cavity-nesting species have shown the strongest associations with urban areas in temperate areas (Chace and Walsh 2006). However, insectivorous, frugivorous, and nectarivorous species are also predominant in some tropical and subtropical urban areas (Brazil and Mexico, Singapore, Australia, respectively; Ortega-Álvarez and MacGregor-Fors 2011a, b). Regarding the traits related to birds able to use the unique array of resources and survive the hazards of urbanization (Emlen 1974), sociability, sedentary, broad diet, longevity, and widespread distribution head the list (Croci et al. 2008; Kark et al. 2007).

Based on a global study of 54 cities, the most common species in cities globally included *Columba livia*, *Passer domesticus*, *Sturnus vulgaris*, and *Hirundo rustica* (Aronson et al. 2014). Across these same cities, the most common bird family was Accipitridae (Table 2.1), not Columbidae, the family containing the ubiquitous rock pigeon (*Columba livia*). In comparing the representation of species within families, we continued our analysis from Aronson et al. (2014) and found that Psittacidae were underrepresented in cities, whereas the families Accipitridae, Anatidae, and Scolopacidae were overrepresented (permutations tests; 9999 samples with replacement; $P < 0.001$). Further, cities harbored the majority of species-level diversity of Anatidae and Scolopacidae (48 % and 59 %, respectively).

Table 2.1 Top ten most common bird families found in the 54 cities of Aronson et al. (2014)

	54 cities		Worldwide		
Family	Number	Proportion	Number	Proportion	% of total
Accipitridae	99	0.049[a]	283	0.025	35.0
Anatidae	87	0.043[a]	183	0.016	47.5
Emberizidae	76	0.037	347	0.031	21.9
Sylviidae	75	0.037	342	0.031	22.0
Tyrannidae	71	0.035	442	0.040	16.1
Muscicapidae	65	0.032	326	0.029	20.0
Scolopacidae	57	0.028[a]	96	0.009	59.4
Columbidae	52	0.025	336	0.030	15.2
Picidae	51	0.025	220	0.021	22.2
Psittacidae	49	0.024[b]	406	0.036	12.1

[a]Bird families with a significantly greater number of species ($P < 0.05$) than expected by chance alone based on the distribution of species within all bird families worldwide
[b]Bird families with a significantly fewer number of species ($P < 0.05$) than expected by chance alone based on the distribution of species within all bird families worldwide

Cities also support threatened and endangered species. Specifically, 14 % of the 54 cities studied housed threatened and endangered species (Aronson et al. 2014). On the other hand, cities are also focal points of species introductions. Of the world's 31 most invasive bird species, 97 % ($n = 30$) were found in cities (Table 2.2). Australasian cities harbor the greatest number of invasive bird species ($n = 176$), followed by cities in the Palearctic ($n = 157$), Nearctic ($n = 127$), Indo-Malay ($n = 108$), and Afrotropic ($n = 65$).

2.3 Patterns and Drivers of Urban Birds

2.3.1 Global and Regional Drivers

Current research has found that urbanization has had a profound effect on the structure of native bird communities at the global scale. In a recent evaluation of 54 cities from around the world (Fig. 2.1), Aronson et al. (2014) found that they housed ~20 % of the world's bird species. Though important, these estimates are clearly not comprehensive for global urban biodiversity as our species accumulation curves that extend Aronson et al.'s (2014) results failed to reach an asymptote (Fig. 2.2), showing that the contribution of cities to global biodiversity is even higher than suggested. In fact we lack knowledge of urban birds from many cities around the world, particularly those in tropical regions and the Southern Hemisphere (but see Bellocq et al. 2016; Chen and Wang 2016).

Across the 54 cities, Aronson et al. (2014) compared different models to explain bird species density in terms of both anthropogenic and non-anthropogenic factors using robust linear regression and an information-theoretic approach with nested

Table 2.2 Prevalence of invasive bird species found in 54 cities

Species	# Cities
Acridotheres fuscus	1
Acridotheres tristis	9
Alectoris chukar	1
Anas platyrhynchos	35
Anser anser	14
Branta canadensis	16
Bubo virginianus	2
Bubulcus ibis	14
Carpodacus mexicanus	10
Circus approximans	3
Columba livia	51
Corvus splendens	3
Cygnus olor	20
Estrilda astrild	5
Gallus gallus	1
Gymnorhina tibicen	4
Leiothrix lutea	1
Molothrus ater	9
Molothrus bonariensis	2
Myiopsitta monachus	3
Oxyura jamaicensis	2
Passer domesticus	48
Pitangus sulphuratus	3
Porphyrio porphyrio	5
Psittacula krameri	16
Pycnonotus cafer	2
Pycnonotus jocosus	4
Streptopelia decaocto	30
Sturnus vulgaris	44
Zosterops japonicus	2

Invasive birds were defined by the IUCN Global Invasive Species Database (http://www.issg.org/database). Across the 54 cities examined 30 of the 31 species were found, with only *Gallus varius* was not found

models (Burnham and Anderson 2002). Following the approach used in Aronson et al. (2014), we found that bird species richness was better predicted by anthropogenic than non-anthropogenic factors (Table 2.3). Human population size and land-cover class had the strongest correspondence with the number of bird species. The age of the cities played a tertiary role suggesting human history has a much more limited role relative to the physical features of the city.

Land cover was expected to be an important predictor of species richness as it defines the quantity and quality of suitable habitats within the city. For the two land cover classes we considered in the current analysis, the number of bird species was

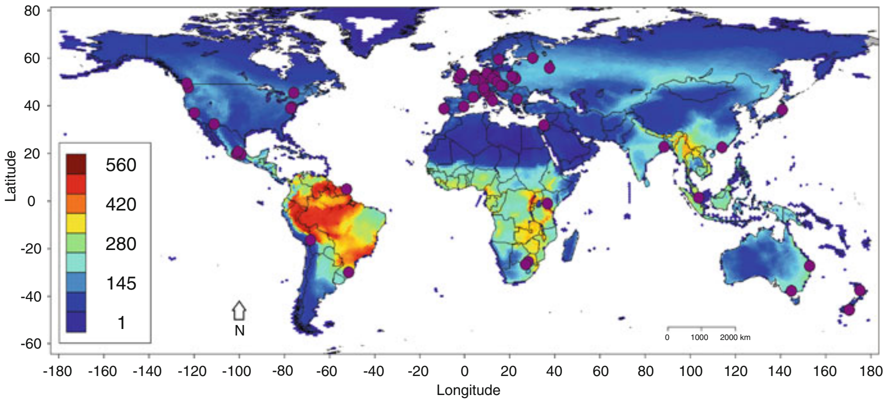

Fig. 2.1 Breeding season species richness for the world's terrestrial birds (10,081 species) summarized within equal-area hexagons (12,452 km^2) of a global icosahedron. The *purple dots* are the locations of 54 cities from Aronson et al. (2014) with richness ranging from 1 (*blue*) to 560 (*dark red*) species per hexagon

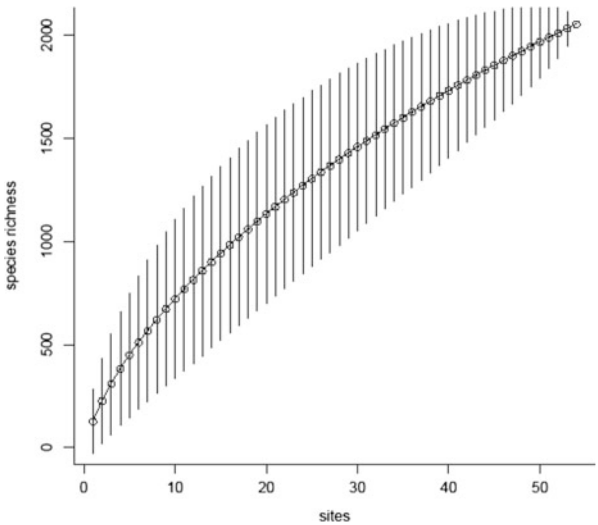

Fig. 2.2 Species accumulation curve based upon the number birds documented from the 54 cities of Aronson et al. (2014). The *vertical lines* are ±2SD where SD were estimated from 100 random permutations of the data

associated with urban land cover and negatively associated with intact vegetation (Table 2.4). These findings may be explained by a variety of factors. First, increasing habitat heterogeneity with urbanization (Desrochers et al. 2011) which leads to higher species richness. Second, the inability of land-cover data to capture small patches of remnant vegetation (300 m resolution). Third, the species-area

Table 2.3 Robust regression models contrasting anthropogenic and non-anthropogenic correlates of bird species richness in cities worldwide

	Bird richness		
Model	AIC_c	$\Delta_i AIC_c$[a]	w_i[b]
Full	132.0	40.3	0.00
Anthropogenic	91.7	0.0	0.74
Population size	94.1	2.4	0.22
City age	104.1	12.4	0.00
Land cover	97.9	6.2	0.03
Non-anthropogenic	160.7	69.0	0.00
Geography	110.8	19.1	0.00
Climate	112.7	21.0	0.00
Topography	102.7	10.9	0.00

[a]Change in model AIC_c ($\Delta_i AIC_c$) represent the difference between model i and the model with the lowest AIC_c score
[b]AIC_c weight (w_i) is the level of evidence for model i based on the entire set of models

Table 2.4 Robust regression coefficients for 12 predictors of bird species richness and proportion of nonnative plants. The predictors are contained within three anthropogenic and three non-anthropogenic models

		Bird richness	
Model	Predictors	Coefficient	*F*
Anthropogenic			
Population size	Population size	0.243	20.05****
Land cover	Urban extent	1.153	10.58***
	% intact vegetation	−0.912	9.22***
City age	Establishment date	0.170	5.28**
Non-anthropogenic			
Geography	Realm	0.207	1.74
	Latitude	−0.304	7.82***
Climate	Temperature	0.032	3.86*
	Temperature seasonality[a]	−0.002	0.17
	Precipitation	0.000	0.04
	Precipitation seasonality[a]	0.003	0.73
Topography	Elevation	0.016	0.12
	Elevation variation	−0.124	2.60

Significant differences for robust *F*-tests are indicated: *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$, and ****$P < 0.001$
[a]Temperature seasonality is the standard deviation of annual temperature *100 from BIOCLIM, and elevation variation is the standard deviation of elevation within a 15 km radius of the city center, a metric of topographic heterogeneity

relationship (Pautasso et al. 2011). Urban land cover and human population size were positively correlated (Pearson $r = 0.58$, $t = 8.68$, $P < 0.001$), whereas intact vegetation and human population size were negatively correlated (Pearson

$r = -0.27$, $t = -3.38$, $P < 0.001$). Cities with larger human populations were also the largest cities in area (Pearson $r = 0.74$, $t = 13.11$, $P < 0.001$).

The transition from native to urban environments resulted in dramatic losses in the density of species found in cities compared to nonurban areas (Aronson et al. 2014). Unlike urban plant communities, the loss for urban bird communities is not compensated through the introduction of nonnative species. Avian assemblages in the 54 cities contained a median of only 3 % nonnative species, which is in strong contrast to the 28 % displayed by urban plant assemblages (Aronson et al. 2014). When considering potential explanations for the current density of native breeding bird species within cities worldwide, anthropogenic features such as land cover and city age were found to be better predictors than the geographical, climatic, and topographic factors typically identified as important predictors of global patterns of diversity (Aronson et al. 2014). These findings suggest anthropogenic drivers take precedence in defining patterns of urban diversity worldwide. When these findings are considered in combination with those from other global urban bird studies, clear management, planning, and conservation recommendations emerge. For example, there is evidence that remnant patches of intact vegetation within urban areas retain macroecological patterns similar to those found in patches of intact vegetation outside urban areas (Pautasso et al. 2011), and large and interconnected patches of intact vegetation are important in maintaining levels of urban bird diversity (Beninde et al. 2015). Thus, the remnant native bird assemblages that occur in urban areas worldwide can be maintained through the development and preservation of interconnected patches of intact vegetation within cities (Daniels and Kirkpatrick 2016).

When examining patterns of urban biodiversity, occurrence information is often more prevalent than abundance information. This deficiency has the potential to obscure the full ecological implications of urbanization. Using North American urban areas as a test case, we present a preliminary analysis exploring the basic associations between patterns of occurrence and patterns of abundance within urban areas. Based on the positive correlation that has often been identified between occurrence and abundance (Gaston et al. 2000), we would expect the most broadly distributed species in North America to also occur with the highest abundance. Moreover, we would expect these patterns to be the most pronounced for broadly distributed nonnative human commensal species, such as the house sparrow (*Passer domesticus*), house finch (*Haemorhous mexicanus*), and European starling (*Sturnus vulgaris*).

Using eBird checklists compiled within North America between 24° and 50° N latitude during the breeding season (June–July) for the years 2002 to 2014 combined, we examined patterns of occurrence and abundance for the ten most commonly occurring urban bird species in two land-cover categories: urban and intact vegetation. Following the methods described in La Sorte et al. (2014), we classified land cover for each eBird checklist using the second edition of the North American Land Cover (NALC) map for 2005 produced by the North American Land Change Monitoring System (NALCMS).

Table 2.5 The ten most commonly occurring bird species in urban areas in North America and the percent of eBird checklists the species was observed in two land-cover categories: urban and intact vegetation

Common	Scientific	Urban	Intact vegetation
American robin	*Turdus migratorius*	48 (5.6)	38 (4.2)
Mourning dove	*Zenaida macroura*	47 (4.0)	31 (3.7)
Northern cardinal	*Cardinalis cardinalis*	44 (3.2)	25 (3.3)
House sparrow*	*Passer domesticus*	39 (8.2)	9 (5.7)
House finch*	*Haemorhous mexicanus*	37 (6.1)	16 (5.6)
American goldfinch	*Spinus tristis*	32 (3.7)	24 (4.0)
Blue jay	*Cyanocitta cristata*	32 (2.6)	22 (2.6)
European Starling*	*Sturnus vulgaris*	31 (11.8)	11 (10.0)
Common grackle	*Quiscalus quiscula*	30 (6.5)	13 (5.9)
Song sparrow	*Melospiza melodia*	30 (3.4)	25 (3.4)

Average abundance is shown in parentheses. Asterisks identify species that are nonnative human commensal

The ten most common urban bird species were widespread North American bird species that occurred in lower proportions in areas of intact vegetation (Table 2.5). Among these ten species were three nonnative human commensals, which were two to three times more prevalent in urban areas (Table 2.5). These three species also tended to be more abundant on average in urban areas (Table 2.5). Our findings suggest urban areas host a greater proportion of commonly occurring North American bird species, and patterns of abundance for these species are skewed toward those having the strongest affinities to human activities and human manufactured environments.

2.3.2 Seasonal Drivers

The primary research focus when considering urban bird diversity has been to examine the structure and composition of breeding bird communities during the breeding season. The breeding season is a critical phase of the annual cycle, and breeding communities are typically the easiest to survey. However, in temperate regions of the Northern Hemisphere, the breeding season lasts only a month or two of the year, and a large proportion of the breeding communities are composed of migratory species (Somveille et al. 2013). How urban bird diversity is defined during other phases of the annual cycle is less common (e.g., Murgui 2010). In particular winter urban bird diversity studies occur less frequently (Jokimäki and Kaisanlahti-Jokimäki 2012; Tryjanowski et al. 2015), and during migration urban bird diversity has rarely been considered.

When species richness and within-year temporal turnover in species composition have been examined across an urban land-use gradient in North America during the full annual cycle (La Sorte et al. 2014), species richness was found to peak across all components of the land-use gradient during spring and autumn migration. However, urban areas tended to have the lowest species richness on average, and urban areas tended to have the lowest within-year temporal turnover in species composition, suggesting that bird diversity within urban areas has been degraded and simplified across all phases of the annual cycle. Another finding to emerge from this work is that these patterns varied geographically, reflecting the influence of different land-cover characteristics and land-use change histories.

However, urban areas do retain a surprisingly high level of relevance for bird communities during migration events. This outcome may simply be due to the high prevalence of urban landscapes within existing migration flyways. Nevertheless, activities directed toward improving the quantity and quality of stopover habitat within urban areas may provide critical support to migratory bird populations during the most vulnerable period of their life cycle.

2.3.3 Local Scale Drivers

Despite the significant contribution of global and regional scale factors, the ability of a bird species to maintain a viable population within a city is ultimately driven by the availability of habitat at the local scale (Evans et al. 2009). As predicted by the species-area relationship, urban bird species richness is strongly correlated with area, both at the scale of the entire city (MacGregor-Fors et al. 2011; Ferenc et al. 2014a) and within individual urban habitat patches (Fernandez-Juricic and Jokimaki 2001; Mörtberg 2001; Chamberlain et al. 2007; Murgui 2007; van Heezik et al. 2013). Within cities, bird species density was highest in cities with the lowest proportion of urban land cover (Aronson et al. 2014), indicating that the provision of green space at the city scale is crucial to bird species conservation in cities (Chace and Walsh 2006; Evans et al. 2009). Similar to whole city studies, urban-rural gradient research has shown that increased urbanization leads to decreased species richness (Lepczyk et al. 2008) but an increase in total avian biomass due to the dominance of a few urban dwelling species (Clergeau et al. 2006; Garaffa et al. 2009).

Within cities a number of factors have been suggested that determine their suitability for birds. These factors include (1) the presence and size of remnant (native) vegetation patches, (2) the presence of nonnative predators, (3) the structure and floristic attributes of planted vegetation, and (4) supplementary feeding by humans (Chace and Walsh 2006). A useful framework for understanding the underlying drivers of these factors is considering urban biodiversity as controlled by either city-level top-down or household-level bottom-up processes (Kinzig et al. 2005). For instance, the extent of green space in cities is largely driven by top-down processes such as government policy (Dallimer et al. 2011), and a challenge to policymakers and conservationists is that the response of urban bird species to the provision of green space can be time-lagged such that contemporary species richness is best explained by historical land cover (Dallimer et al. 2015). In addition to the extent of urban habitat, birds also respond to the connectivity and configuration of urban green space(e.g., Fernandez-Juricic 2000; Pellissier et al. 2012) suggesting an important role for urban planners in the design of green infrastructure strategies.

Bottom-up processes that reflect the collective decisions of individual households and communities can lead to both positive and negative outcomes for birds. For example, the decision to keep an outdoor domestic cat can have major negative implications for urban bird communities (Lepczyk et al. 2004b; Sims et al. 2008; van Heezik et al. 2010; Bonnington et al. 2013; Belaire et al. 2014). On the other hand, vegetation composition and structure can positively influence bird diversity in a wide variety of urban habitats, including parks and public gardens (Shwartz et al. 2008; Paker et al. 2014), domestic gardens (Daniels and Kirkpatrick 2006; Belaire et al. 2014), remnant native vegetation (Palmer et al. 2008; Davis et al. 2013), and business parks (Hogg and Nilon 2015). Notably, there is evidence that native vegetation is important for supporting native avifauna (Daniels and Kirkpatrick 2006; Burghardt et al. 2009; Lerman and Warren 2011). Although planting and landscaping in public parks are largely the product of top-down decisions (Kinzig et al. 2005), the ability for householders to buy and maintain vegetation is driven by socioeconomic and personal choices (e.g., Hope et al. 2003; Lepczyk et al. 2004a; Martin et al. 2004; Lubbe et al. 2010). In fact, a positive relationship between householder neighborhood socioeconomic status and bird diversity has been widely documented (Kinzig et al. 2005; Melles 2005; Strohbach et al. 2009; Lerman and Warren 2011; Luck et al. 2013). Besides planting and landscaping decisions, people also directly influence the provision of food for birds in cities through supplementary feeding, and this has been shown to effect bird populations at multiple spatial scales (Robb et al. 2008; Fuller et al. 2008, 2012). In the USA and UK, the decision to feed birds is driven by a complex range of socioeconomic and demographic factors (Lepczyk et al. 2012; Goddard et al. 2013).

2.4 Next Steps in Urban Bird Ecology

2.4.1 Questions in Basic Ecology

Although our understanding about the urban ecology of birds has advanced markedly in recent years, there remain several key areas in need of further research, including demography, disease, behavior, and species interactions. We highlight demography and disease ecology as being among the two areas most critically in need of investigation. However, behavioral studies are proliferating rapidly, revealing the simultaneous capacity of birds to adapt to the novel conditions found in cities (reviews in Gil and Brumm 2014) as well as the impacts of behavioral constraints in limiting species distributions. Unresolved debates over the role of species interactions in structuring urban bird communities illustrate the need for additional mechanistic studies of predation (Rodewald and Kearns 2011; Stracey 2011; Fischer et al. 2012) and competition (Rodewald and Shustack 2008; Shochat et al. 2010; Farwell and Marzluff 2013).

Demographic studies are urgently needed to complement the many occupancy and abundance studies of birds in urban areas. Without demographic data and analyses, it is impossible to determine the likelihood of persistence for species present in urban areas. One meta-analysis found reduction in clutch sizes, nestling weight, and productivity per nesting attempt in urban relative to paired nonurban bird populations (Chamberlain et al. 2009). These differences might be counterbalanced, however, by earlier and/or longer breeding seasons and increased numbers of nesting attempts (Reale and Blair 2005; Deviche and Davies 2014). As a result, the net effect of urbanization on population trends is unclear for most species. Furthermore, some urban land-use types support higher levels of reproductive success than others (e.g., Marzluff et al. 2007; Stracey 2011). Thus, studies are needed that address heterogeneities in avian productivity within urban areas.

Diseases can fundamentally alter urban bird communities, as exemplified by the high-profile West Nile virus which has the potential to dramatically impact avian populations (Kilpatrick et al. 2007). There are many other less well-known pathogens affecting urban birds (Robinson et al. 2010; Martin and Boruta 2014), such as intestinal coccidians (Giraudeau et al. 2014), which may be implicated in reductions in plumage coloration with urbanization (Giraudeau et al. 2015). Within cities, lower income areas may receive the brunt of disease outbreaks when economic declines and disinvestment are associated with habitat for pathogen hosts (e.g., Davis 1953; Harrigan et al. 2010). In addition, supplementary feeding has been cited as a potential factor in outbreaks of a wide variety of avian diseases (Martin and Boruta 2014). But insufficient information exists as yet to predict how feeders affect rates of infection and disease outbreaks. Interestingly, though, a variety of studies have found that urbanization may actually *reduce* the spread or impact of disease, while in other cases, it appears to exacerbate rates of infection (Bradley and Altizer 2007; Martin and Boruta 2014). Such differences in relationships suggest that the kind of host and mode of transmission may be important in determining how urbanization affects the prevalence of avian diseases. Finally, there are important potential feedbacks between avian health and human health related to disease that need further exploration (Strohbach et al. 2014).

2.4.2 Managing for Birds in Cities

Research conducted at multiple scales has important repercussions for managing birds in cities. Global-scale data are important because they allow us to understand how large-scale factors affect bird distributions and how cities differ or are similar in how they support bird diversity. Furthermore, global data analyses allow for generalizations on landscape-scale characteristics that are important for birds. On the other hand, local-scale data allows us to understand what factors are important for particular species or populations of particular species.

At the local scale, urban bird species appear more sensitive to local habitat features than landscape factors (Evans et al. 2009), providing considerable opportunities for enhancing avian diversity through management. Management recommendations based on associations between vegetation variables and bird species richness and diversity in urban green spaces have often been made at the city scale (e.g., Palmer et al. 2008; Belaire et al. 2014; Ferenc et al. 2014b), but to make robust generalizations requires standardized data on bird-habitat associations from multiple cities (Fontana et al. 2011; Lerman et al. 2014). Furthermore, such data are needed from cities occurring in areas of high regional biodiversity, such as tropical cities and cities within biodiversity hotspots (Aronson et al. 2014), as urbanization is occurring at a rapid pace (Fragkias et al. 2013).

Even with additional data, management recommendations may not be universally applicable. For example, supplementary feeding has been shown to have positive effects in the UK (Fuller et al. 2008, 2012), but detrimental effects in Australia where bird feeding is discouraged (Jones and Reynolds 2008). Other management recommendations, such as increasing the amount of dead wood (Sandstrom et al. 2006), the addition of standing water (Ferenc et al. 2014a), and reduced management of urban parks (Shwartz et al. 2008), will require reconciling human safety and public perception with the needs of the urban avifauna. Furthermore, work from Australia, the USA, and Israel suggests that the presence of native vegetation in urban yards benefits the bird community (Daniels and Kirkpatrick 2006; Burghardt et al. 2009; Lerman and Warren 2011; Paker et al. 2014), but there are no corroborating results from Europe to date. With the exception of Burghardt et al. (2009), who were careful to select pairs of yards that differed only in the proportion of shrub and groundcover that consisted of native plants, no studies have been designed to explicitly test for the effect of native versus nonnative vegetation on bird diversity. Likewise, many of the other management recommendations would benefit from experimental manipulations to deepen our understanding of the mechanisms that structure urban bird communities (Shochat et al. 2006). For example, Lerman et al. (2012b) used artificial food patches to examine differences in foraging behavior between mesic (lush, exotic vegetation) and xeric (drought-tolerant, native vegetation) yards in Phoenix, USA, and showed that xeric yards constituted a superior avian habitat. Larger-scale experiments across multiple cities are emerging for other taxa such as pollinators (e.g., the UK Urban Pollinators Project: http://www.bristol.ac.uk/biology/research/ecological/community/pollinators/background/question3/), but comparable avian studies are lacking.

Effective management of urban ecosystems requires coordination across multiple spatial scales and across multiple stakeholders (Goddard et al. 2010; Gaston et al. 2013). Most bird species cannot maintain a viable population within a single habitat patch, but instead utilize urban green spaces at relatively broad spatial scales (Hostetler and Holling 2000) and will therefore respond to habitat heterogeneity at the landscape scale (Litteral and Shochat 2016). How best to manage a network of green spaces (the vast majority of which are owned and managed by many different stakeholders) to maximize bird diversity within a given city remains a key challenge. One possibility is the creation of a mosaic of habitat zones across a city, wherein private gardens and other urban green spaces are managed under a common theme (Goddard et al. 2010). Such an approach would be most effective if implemented as new housing schemes are planned and designed, perhaps as part of conservation development (Reed et al. 2014) and could also include a mechanistic component by embedding a designed experiment within the new development (Felson and Pickett 2005). In addition to working with city planners and housing developers, ecologists also need to engage with social institutions operating at relevant scales for coordinated biodiversity management. For instance, Lerman et al. (2012a) show that neighborhoods belonging to a homeowner association had significantly greater bird diversity than other neighborhoods, which could potentially be explained by the presence of top-down sanctions enforcing certain landscaping designs.

Managing for birds could also spread through bottom-up processes, such as neighbor mimicry (Warren et al. 2008; Goddard et al. 2013). Such social processes could be facilitated by citizen science programs that provide residents with positive feedback about management activities that benefit birds (Cooper et al. 2007; van Heezik et al. 2012). Likewise, educational outreach programs could also target urban planners and policymakers (Hostetler 2012). However, it remains the case that more sociological-based studies are required to understand how best to incentivize householders and other urban land managers into a bird-friendly management. These studies should address further how urban habitat management attitudes and behavior vary with culture, socioeconomic, and demographic factors (Kirkpatrick et al. 2012; Lepczyk et al. 2012). Subsequent recommendations will be most effective when they are specifically geared to different stakeholders (Snep et al. 2015).

2.4.3 Cities and Climate Change

Though climate change has been a central topic of concern in ecology and conservation biology, our understanding of how it may affect birds in cities remains elementary. Bird diversity does relate directly to how variable the energy from year to year is at given location on earth (Rowhani et al. 2008), and urban areas in the USA show much less interannual variability than rural areas (Linderman and Lepczyk 2013). Such findings suggest that cities may represent relatively more stable systems than those surrounding the city and could thereby provide some refuge for urban birds. However, climate change is altering both temperature and precipitation patterns, both of which have well-established relationships with survival and reproduction in birds as measured in local weather patterns (Chase et al. 2005; Preston and Rotenberry 2006; Wright et al. 2009; Skagen and Adams 2012). Thus, understanding how changes in local-scale weather will influence urban birds is needed.

Climate change has already been related to changes in bird phenology (Root et al. 2003) and changes in bird diversity in cities (La Sorte and Thompson 2007). Furthermore, because species respond differentially to climate change (Wiens et al. 2009), how geographic ranges will change in relation to one another, particularly in relation to urban areas, remains to be seen. As many cities are now working on developing climate change adaptation plans, it will be important to link such plans with how they affect both bird habitat and the birds themselves.

2.4.4 Monitoring

In order to have full understanding of species and their populations over space and time requires sound monitoring (for the necessity of a temporal perspective in bird urban ecology see Fidino and Mason 2016). Though several well-established monitoring programs (e.g., the North American Breeding Bird Survey, Audubon's Christmas Bird Count) and international surveys (e.g., BirdLife International Global Survey on the Status of Urban Bird Conservation) have proved key in our understanding of avian ecology (e.g. Fergus et al. 2013; La Sorte and Thompson 2007; Lepczyk et al. 2008; Pidgeon et al. 2014), we lack in having monitoring programs that are unified in methodology across cities of the world. Furthermore, we simply lack monitoring of any type for many locations previously highlighted, making not only comparative questions challenging, but resulting in a lack of knowledge about the fates of many species. What would be beneficial is a global monitoring program, perhaps akin to eBird, that could account for habitat/environmental conditions and would be feasible to use in the tropics and Southern Hemisphere, where we lack knowledge on urban systems.

2.5 Conclusions

The resurgence of urban ecology in the past several decades has greatly advanced our knowledge of urban avian ecology from local to global scales. However, as urbanization continues, the human population grows, and climate changes, we have many remaining challenges in understanding relationships between birds and cities. In order to effectively preserve bird diversity in cities, the following research and management efforts are needed. First, we lack monitoring programs that are unified in methodology across cities of the world (see van Heezik and Seddon 2016 for a review on censusing birds in urban areas). A number of cities do have urban bird monitoring programs (e.g., Turner 2003; Murgui 2014) and elements of such programs could be utilized to develop a robust urban bird monitoring program across the cities of the world. Such a unified methodology is needed if we are to have a more complete understanding of urban birds and develop appropriate management guidelines at the correct scales. Second, we lack information about birds from much of the Southern Hemisphere's cities, particularly those in lesser developed nations, the tropics, and urban areas on islands. As a result, our present understanding is dominated by Northern Hemisphere temperate systems, which may differ from urban areas in other parts of the world. Third, we need to focus attention on urban birds in and near biodiversity hotspots and locations experiencing rapid rates of urbanization. Finally, we need to continue researching basic ecological aspects of urban birds.

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