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Advancing urban wildlife research through a multi-city collaboration

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Research on urban wildlife can help promote coexistence and guide future interactions between humans and wildlife in developed regions, but most such investigations are limited to short-term, single-species studies, typically conducted within a single city. This restricted focus prevents scientists from recognizing global patterns and first principles regarding urban wildlife behavior and ecology. To overcome these limitations, we have designed a pioneering research network, the Urban Wildlife Information Network (UWIN), whereby partners collaborate across several cities to systematically collect data to populate long-term datasets on multiple species in urban areas. Data collected via UWIN support analyses that will enable us to build basic theory related to urban wildlife ecology. An analysis of mammals in seven metropolitan regions suggests that common species are similar across cities, but relative rates of occupancy differ markedly. We ultimately view UWIN as an applied tool that can be used to connect the public to urban nature at a continental scale, and provide information critical to urban planners and landscape architects. Our network therefore has the potential to advance knowledge and to improve the ability to plan and manage cities to support biodiversity.

We live on a human-modified planet (Acuto *et al.* 2018), and in no environment is this more apparent than in the world's cities. Of the Earth's total land surface area, >10% is now characterized as urban land cover (McGranahan 2005), and the

In a nutshell:

- Cities are rapidly expanding around the planet and emerging as a new ecosystem for wildlife
- To maximize the potential of cities as habitat, scientists and managers need a broader understanding of the ecology and behavior of wildlife in cities, a perspective that is currently limited in urban wildlife research
- To overcome these limitations, we designed a network of research partners (the Urban Wildlife Information Network or UWIN) who are collaborating across cities to systematically collect long-term data on mammals in a coordinated fashion
- UWIN has the potential to improve the long-term coexistence between humans and wildlife by advancing ecological theory, influencing how urban planners can design cities that are more wildlife-friendly, and connecting people to nature in an unprecedented way

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continued pace of urbanization is astonishing (Acuto *et al.* 2018). The majority of the planet's human population now lives in urban areas, and the global urban population is expected to increase to nearly 5 billion people by 2030 (Seto *et al.* 2012). The unprecedented expansion of urban areas will undoubtedly continue to transform the ecology of the world, with profound consequences for biodiversity worldwide (McKinney 2008).

As the newest and fastest growing ecosystems on the planet, cities also represent a unique opportunity for science, particularly ecology and conservation (Miller and Hobbs 2002). The number of people living in human-modified areas provides an untapped and valuable opportunity to engage the public in the process of ecological research (Dickenson *et al.* 2012) and to connect people to nature (Miller and Hobbs 2002). For cities to be part of conservation solutions, cultivating an appreciation for urban flora and fauna among human city dwellers will be necessary (Berry 2013). Connecting people to nature through careful city planning could therefore have tremendous potential as a way of conserving nature and biodiversity. This approach, termed "reconciliation ecology" by Rosenzweig (2003), could facilitate wildlife conservation even in the heart of urban landscapes.

Although cities are not typically built with wild flora and fauna in mind, they do contain important wildlife habitats, such as parks, nature preserves, golf courses, cemeteries, and in some cases even yards (Gallo *et al.* 2017; Belaire *et al.* 2014). Moreover, efforts to incorporate natural habitats into urban planning –for conservation, to improve human well-being, or to increase property values – are increasingly common (Beatley

2011). At the same time, many wildlife species are recolonizing urban areas (Smith *et al.* 2014), ultimately increasing the likelihood of human–wildlife interactions. Urban wildlife species already interact frequently with humans, due in part to the high density of people that live and work in cities (Soulsbury and White 2016). Although the majority of human–wildlife interactions are either positive or harmless (Soulsbury and White 2016), some negative interactions do occur (Adams and Lindsey 2010), and this can be counterproductive to conservation efforts. Such negative interactions include property damage, attacks on people or pets (Bjerke and Østdahl 2004), and the transmission of zoonotic diseases (Jones *et al.* 2008). Maximizing positive interactions and limiting human–wildlife conflicts should therefore be conservation priorities, but this will first require a better understanding of urban wildlife behavior and ecology (Magle *et al.* 2012).

Current state of urban wildlife research

Specific information about urban wildlife diversity, and how animals adapt to and persist in cities, is limited, but some general patterns are beginning to emerge from the primary literature. For example, studies have shown that the overall diversity of wildlife tends to decrease within urban areas (Aronson *et al.* 2014) and that wildlife diversity is lowest in the most highly urbanized environments, yet species densities also tend to be higher in urban areas than in non-urban settings (McKinney 2006). Although the specific mechanisms associated with wildlife persistence in cities are complex and vary among species, general patterns have emerged. For instance, species with specialized diets and habitat requirements are less likely to thrive in urban areas than generalist species (Ordeñana *et al.* 2010). Very large mammalian predators are typically unable to live in cities due to persecution by humans (Ordiz *et al.* 2013) and their need for large tracts of habitat (Bateman and Fleming 2012), but even these broad trends are not observed universally across all cities and taxa (Gehrt *et al.* 2010). Mountain lions (*Puma concolor*) are large carnivores but are fairly common, albeit at low densities, in urban areas across the western US (Gehrt *et al.* 2010).

Although some general patterns and trends have been identified, existing studies have numerous limitations that restrict our understanding of urban wildlife ecology and behavior. Most research focuses on a single species, particularly mammals and birds (Magle *et al.* 2012), which reduces our ability to understand community dynamics and interspecific interactions, such as avoidance and co-occurrence (Magle *et al.* 2012). In addition, studies are often limited to the short term (eg 1–3 years), making it difficult to estimate long-term effects of urbanization on wildlife species (Magle *et al.* 2012). Finally, to date, ecological predictions for urban wildlife behavior and distributions are typically based on theoretical models derived from non-urban systems; yet such models are rarely applicable to urban ecosystems (Magle *et al.* 2014).
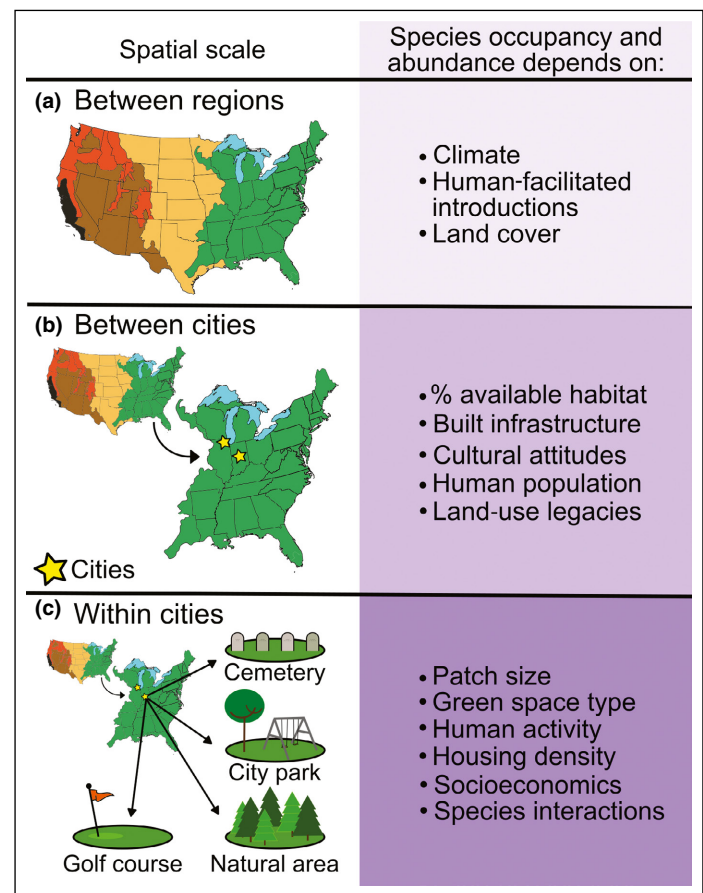
Figure 1. The diversity and abundance of urban wildlife communities are determined by factors at varying hierarchical scales. Large-scale distributed research networks like the Urban Wildlife Information Network (UWIN) can address ecological questions at all three spatial scales ([a], [b], and [c]), whereas single-city studies only function at the smallest spatial scale (c).

However, the single-city focus of most studies is perhaps the most restrictive aspect of current urban wildlife research (Magle *et al.* 2012). Individual cities are unique, and characterized by extreme variation in attributes such as size, geography, age, context, topography, hydrology, zoning, growth patterns, land-use legacies, and culture (Figure 1; Pacione 2009). Wildlife responses to this variation likely differ among and within cities due to these varying factors, making it difficult to extrapolate findings to other urban areas (Aronson *et al.* 2016). Unless we broaden our research beyond this single-city focus, scientists will only be able to describe the behavior and distribution of species locally, and will be unable to detect global organizing principles or wide-ranging patterns that could generate broad recommendations for urban design and conservation (Figure 1). Globally distributed studies have recently become more common in ecology, and have the potential to overcome limitations inherent to locally focused studies (Borer *et al.* 2014). These international studies can allow researchers to identify generalities across spatial and temporal scales if they are based on comparable treatments and sampling, have clear ground rules for participation, and consist of simple, inexpensive, and flexible designs.

Here, we describe a new, collaborative, distributed study design for urban wildlife research that enables simultaneous data collection of species distributions across multiple taxa and in numerous cities. Although there are wide-ranging wildlife programs that vary in focus (eg eMammal, UrBioNet) and broad-ranging urban ecological programs (eg National Center for Ecological Analysis and Synthesis, Baltimore Ecosystem Study, and Central Arizona–Phoenix Urban Long-Term Ecological Research program), the partnership we describe is the first of its kind to employ systematic protocols and data collection systems for urban wildlife research across multiple cities. Some networks with proscribed sampling designs are more centrally managed (eg National Ecological Observatory Network), whereas others involve protocols for data collection but not for site selection and sampling design (eg eBird, eMammal). Our approach allows both autonomy among partners (distributed network) and the implementation of shared protocols focused solely on urban wildlife research. This network – the Urban Wildlife Information Network (UWIN) – is designed to facilitate identification of key patterns and phenomena that may represent first principles of urban wildlife ecology, as well as to support conservation and management recommendations specific to individual cities and towns.

■ A multi-city network for collaborative and systematic urban wildlife research

The UWIN protocol uses a collaborative approach to biodiversity monitoring in urban areas that is flexible enough to be adapted to multiple cities but methodical enough to allow for direct comparisons between cities. This research approach focuses on the long term (on the order of decades) and is relatively inexpensive. The study design enables researchers to test foundational hypotheses that are central to the new scientific discipline of urban wildlife ecology (eg mesopredator release; Crooks and Soulé 1999) at broad spatiotemporal scales. Investigators are able to begin to account for intercity variability to identify the broad-scale mechanisms that dictate how global urbanization affects spatiotemporal patterns in biodiversity, and can make recommendations relevant to developing urban landscapes to benefit both humans and wildlife.

A common design

UWIN's research design, which has been implemented in Chicago, Illinois, since 2009, is centered on the establishment of at least 25 long-term research sites in each city (currently, 19 cities participating, mean number of sites per city = 50.6) along spatial gradients of urbanization (McDonnell and Pickett 1990; Seress *et al.* 2014), radiating from the urban core of the city through suburban, exurban, and rural areas. The gradient approach was chosen because simply delineating sites into arbitrary categorizations such as "urban"

and "non-urban" obscures potential differences within categories, and makes comparisons between regions more challenging (Seress *et al.* 2014). However, because the design is also modular, specific portions of the sampling transect can be subsampled (eg isolating suburban habitats) to answer targeted research questions. Sites are selected to encompass a range of urban green spaces (ie potential wildlife habitats), including nature preserves, city parks, golf courses, cemeteries, and backyard habitats (Magle *et al.* 2014). More details are available at www.urbanwildlifeinfo.org.

To date, a central focus has been on monitoring medium- and large-sized mammals using motion-triggered cameras (Figures 2 and 3; WebPanel 1; see Magle *et al.* [2014] for details). This approach is a useful starting point because the sampling is passive, and the equipment is both relatively inexpensive (~US$200 per camera setup) and easy to use and maintain. Within field sites, camera traps are deployed four times per year for a minimum of 28 days per deployment to capture seasonal variation in the distribution of medium- to large-sized mammals, with cameras always spaced at least 1 km apart to reduce spatial autocorrelation (Magle *et al.* 2014). Although some urban mammals, such as coyotes (*Canis latrans*), have home range areas whose radiuses exceed this level of separation between sites, 1 km was chosen because this distance is greater than the radiuses of the home ranges of most urban adapted species (Gehrt *et al.* 2010). Furthermore, standard and readily available covariates – such as impervious surface, canopy cover, and road and housing densities, among others (Magle *et al.* 2014; Gallo *et al.* 2017) – exist across partnering cities at this spatial grain. Theft and vandalism of research equipment is always a concern in urban regions, but the rate of destruction of cameras has been <2% per deployment in every city where data have been collected so far.

Although mammalian monitoring is a useful starting point, the UWIN protocol is not taxon-specific, and lends itself effectively to point or line transect counts for avian abundance and diversity (Marzluff *et al.* 2012), sampling of amphibians and reptiles via cover boards (Sullivan *et al.* 2017), pitfall or interception traps for insects (Braaker *et al.* 2014), ultrasonic monitoring of bats (Gallo *et al.* 2017), vegetative sampling (Threlfall *et al.* 2016), and countless other types of surveys. Maintaining a large number of study sites indefinitely (Borer *et al.* 2014) allows investigators to monitor how species respond to urbanization both spatially and temporally.

Partner city designs

Cities are often considered to have a homogenizing influence on biota, promoting certain species that become regionally and locally abundant at the expense of less well-adapted species (McKinney 2006). Yet important differences exist among cities as well; for example, the cities we monitored vary greatly in size, landscape and ecoregional context, location (latitude/longitude), historical context (eg the era in which a city experienced its major period of growth; Aronson

Figure 2. (a) An early research focus of UWIN has been the monitoring of medium- to large-bodied mammals using remotely triggered wildlife cameras. (b) Ringtail (*Bassariscus astutus*) in a city park in Austin, Texas; (c) coyote (*Canis latrans*) in a cemetery in Chicago, Illinois; and (d) red fox (*Vulpes vulpes*) in a riparian corridor in Indianapolis, Indiana.

et al. 2016), and population density (Table 1). We hypothesize that such factors likely influence the regional pool of species available to colonize cities and may alter the relative abundance of species present (Figure 1).

There is a critical trade-off between standardization and flexibility, given the diverse geographies of and logistical constraints imposed by each city. Although all UWIN partners are required to use similar designs to ensure data comparability, wildlife in each city is sampled along varying gradients of urbanization and transect configurations (WebPanel 2; Figure 4). The shared gradient design ensures that data are comparable, because they are collected across all available habitat types; however, flexibility in transect design is critical to capture the variation in urban form within each city, and to make certain that each partner can conduct the study within the constraints imposed by local conditions.

Data ownership and management

Each UWIN partnering institution retains autonomy and ownership of their own data, but is also part of a network that enables broader application through cross-regional comparisons. Memorandums of Understanding provide mutually agreed-upon conditions for sharing data. UWIN employs a standard database infrastructure (Ivan and Newkirk 2016) so that all data are entered identically and remain readily comparable. Each partnering institution maintains its own portion of the database, and multi-city analyses are conducted by combining processed data collected from each city. To ensure entered data are validated and to standardize queries for data analysis, we have designed an R package, uwinr, that can be used to check a database for data entry errors, provide reports of those errors, and generate data structures for varying analyses (Fidino 2017). Several partners use a community-based approach for identifying animals in photo data (eg Simpson *et al.* 2014), whereas others rely solely on expert identification. At present, a cloud-based centralized data storage platform is under construction for UWIN.

Design conclusion

For a continental-scale research platform, design and implementation are critical. Our design meets the major requirements for globally distributed studies (Borer *et al.* 2014), including clear scientific goals and questions (Figure 1); identical treatments and sampling; well-defined ground rules for participation; a relatively simple, inexpensive, and flexible design; and a plan for data management.
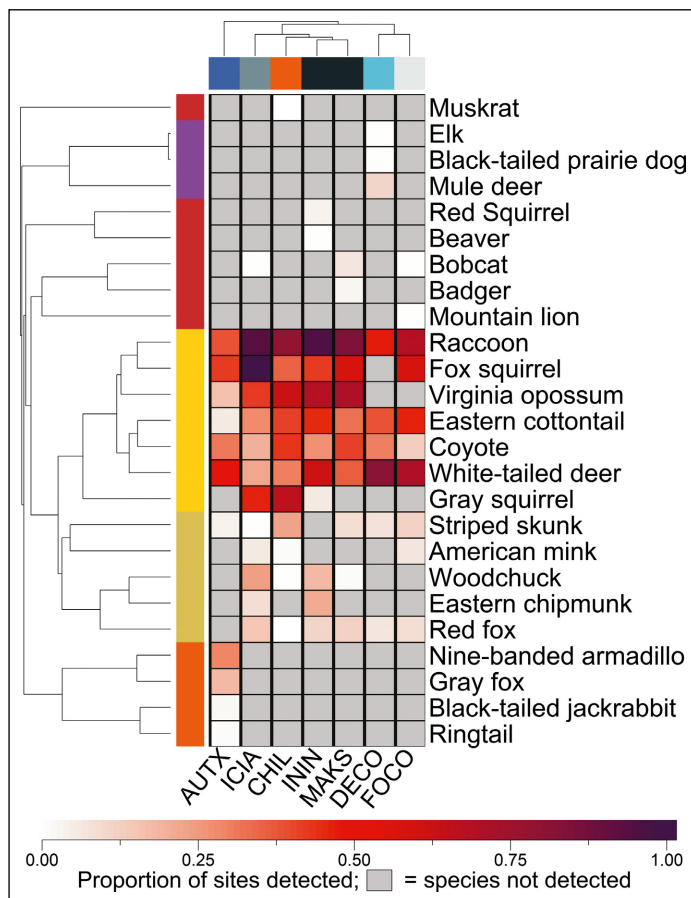
Figure 3. Cities greatly differed in the wildlife species present and their spatial distribution. This figure represents the proportion of sites at which each species was detected across seven US cities. The top dendrogram represents the compositional associations of urban mammal communities between cities, which terminate at the unique groups (the stacked vertical colors). The left-side dendrogram represents the compositional associations between species (the horizontal colors). City abbreviations: MAKS = Manhattan, Kansas; CHIL = Chicago, Illinois; ININ = Indianapolis, Indiana; ICIA = Iowa City, Iowa; FOCO = Fort Collins, Colorado; AUTX = Austin, Texas; DECO = Denver, Colorado.

Broader impacts

Broader impacts, management recommendations, and policy insights are made possible by systematically collected, broad-scale data. UWIN data collection is intended to provide fundamental information about wildlife distributions and behavior to practitioners and policy makers. We ultimately view the network as an applied tool for connecting the public to urban nature at a continental scale, and providing critical information to urban planners, wildlife managers, and landscape architects.

Planning and policy

UWIN-generated data have already been the source for several publications in the primary literature (eg Gallo *et al.* [2017] and references therein), but the reach of the network extends beyond the scientific community. Results generated by UWIN can influence planning and policy throughout a given region, benefiting both wildlife and people. Our long-term data have been used to compare wildlife distributions before and after major developments or habitat restorations (eg Chicago's Burnham Wildlife Corridor, City of Manhattan's [Kansas] Park at Lee Mill Heights), which helps investigators to assess the impact of restoration and development on wildlife, as well as guiding urban planning more generally. For instance, park planners and managers in Manhattan, Kansas, are currently using UWIN data as baselines for urban wildlife communities to ensure parks and natural areas contain suitable habitat for urban wildlife. UWIN members also consult with regional nature agencies (eg the Mayor's Committee for Nature and Wildlife in Chicago), and have formed partnerships with several organizations, such as the American Architectural Foundation, to develop recommendations for urban design.

The predictive power and ecological scope of UWIN will continue to expand as more cities join the network. The data collected will not only enable an enhanced understanding of urban wildlife ecology and behavior, but will also influence urban planning and policy in ways that improve the public's

Table 1. City-specific variables across the seven US cities in the Urban Wildlife Information Network

City	Latitude (DD)	Longitude (DD)	Population density (people/km^2)	City area (km^2)	Number of sites with ≥25 observation days
Austin, Texas	30.27	−97.73	1827.48	770.64	22
Chicago, Illinois	41.87	−87.62	2978.69	589.32	88
Denver, Colorado	39.73	−104.98	2072.73	396.03	39
Fort Collins, Colorado	40.58	−105.08	1027.45	140.35	27
Iowa City, Iowa	41.65	−91.52	682.59	64.69	35
Indianapolis, Indiana	39.77	−86.15	1144.17	949.02	38
Manhattan, Kansas	39.18	−96.57	486.22	48.66	67

Notes: A camera-trapping location (ie site) was used in the analysis only if there were at least 25 functional camera-trapping days between July and August 2017. Population density was calculated as the average number of people within 1 km of a camera trap in each city.
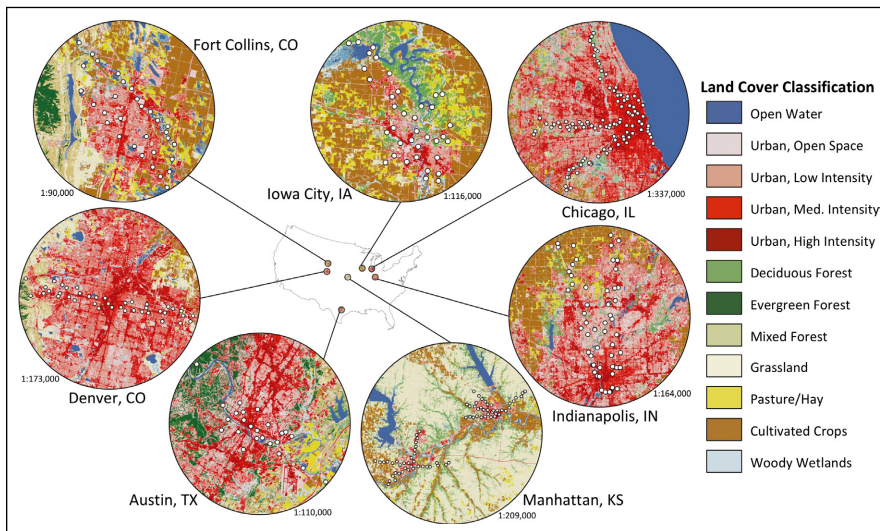
Figure 4. The UWIN design is sufficiently flexible so that it can be adapted for use in multiple cities, while its systematic collection of data allows for direct comparisons across cities. Shown here are the geographic locations and configuration of study sites for each of the seven cities included in the preliminary analysis. Each white dot represents an individual sampling site. Base layer: 2011 National Land Cover Database (Homer *et al.* 2015).

ecological literacy while simultaneously reducing human–wildlife conflict. For example, knowledge about how animals colonize new patches through time, and thus move through the urban matrix, will make it easier to predict road-crossing locations for different species and can therefore inform placement of signage or underpasses (Forman *et al.* 2003). Additionally, identifying species–habitat relationships in urban green spaces provides empirical support for management recommendations that benefit various species of wildlife. As such, UWIN can provide concrete guidelines for urban green development.

Connecting people and nature

Although the ecological and conservation potential of this network is enormous, the opportunities that it provides for community members of all ages to engage in research are also extremely valuable (Figure 5). Public participation in research can improve science literacy and generate a sense of place, which is especially important in urban areas, where the general public experiences a greater disconnect from nature (Brewer 2002). By conducting similar studies that have parallel goals we can more quickly refine and improve our pedagogical tools to educate both students and the public. Education, outreach, and public participation in science efforts can be managed through UWIN, connecting students and the public across geographic regions as they learn about local species.

In Austin, Texas; Chicago, Illinois; Fort Collins, Colorado; and Indianapolis, Indiana; UWIN partners have engaged with K–12 students from primarily underserved communities to become active participants in biodiversity monitoring. In Denver, Colorado, the UWIN context and data have been incorporated into a Course Based Undergraduate

Research Experience (CURE; see Brownell *et al.* [2015] for a description of CUREs) that reaches approximately 400 biology students each semester at the University of Colorado–Denver. In Indianapolis, programs featuring data generated by UWIN projects have been presented to over 5000 people at 13 different community engagement events. In Chicago, high-school students contribute data to UWIN as part of the Partners in Fieldwork program, a program modeled after scientific techniques employed by UWIN researchers (Mulligan *et al.* 2015). Students deployed cameras on school grounds along the Chicago study transects and complemented the camera data with bird surveys and bat monitoring. Through pre- and post-knowledge questionnaires from 2013 to 2015, program leaders found that students listing urban wildlife as "playing an important role in the environment" increased from 23.8% before the program to 42.5% after program completion ($n = 160$), whereas negative responses such as "urban wildlife are pests" and "it's not important to me" decreased from 8.1% and 23.8% to 0% and 11.3%, respectively (Mulligan *et al.* 2015). Students increased their knowledge of local wildlife; indeed, 73% of classroom instructors indicated that their students demonstrated a better understanding and awareness of nature, while 91% stated the program increased scientific understanding and served as an excellent real-world example to support their scientific curriculum ($n = 11$; Mulligan *et al.* 2015). These efforts allow researchers access to new study sites (eg school grounds) while engaging students in active learning that reinforces core curriculum concepts.

UWIN also offers a platform and resources to create community science projects specific to each city. Currently, UWIN partners in Chicago and Austin work with >7000 volunteers from around the world to identify animal species captured in camera images through Zooniverse web portals (eg Chicago Wildlife Watch [www.chicagowildlifewatch.org], which has provided roughly one million "tags" across a total of 200,000 images). This collaboration with Zooniverse helps in the preparation of data for analysis while also connecting the users to local wildlife (Simpson *et al.* 2014). In Iowa City, Iowa, UWIN partners are engaged in species documentation and public outreach with multiple local non-profit land trust organizations, and other cities across UWIN are currently implementing similar efforts to engage community scientists.

People in urban areas, especially children, often lack knowledge and education about the natural world (Louv 2008). Moreover, the "extinction of experience" phenomenon, which describes the increasing disconnect between people and nature in cities, can lead to a decline in pro-environmental attitudes

Figure 5. UWIN partners participate in various forms of outreach, connecting students and the public across geographic regions to their local ecosystems. (a) Coauthor TG (Chicago) leads a group of art students from the Chicago Museum of Contemporary Art and Columbia College through a day of fieldwork; students were participating in an installation that focused on urban green spaces. (b) Coauthor LH (Denver, not pictured) discusses wildlife research with a group of 3–5-year-old students in the Denver, Colorado area. (c) University students work with coauthor AB (Austin) to install cameras along Waller Creek in Austin, Texas, as part of a joint partnership between the Waller Creek Conservatory, the Texas chapter of The Nature Conservancy, and the University of Texas.

and behavior over time (Soga and Gaston 2016). By learning about the unique wildlife communities in each city while describing what they have in common, we hope to connect more people to wildlife and inspire new generations of urban naturalists.

Conclusions

Because urbanization will continue to accelerate in the foreseeable future, it is critical to achieve an improved understanding of urban ecosystems. However, ecologists and resource managers cannot begin to conserve urban wildlife at a broad scale without understanding the variation present within and among cities. UWIN is beginning to elucidate the mechanisms that affect urban wildlife ecology across cities (WebPanel 1). Describing and predicting differences and commonalities among cities and regions are initial steps toward an improved understanding of how urban wildlife populations and communities form and persist, and how they interact with humans, both positively and negatively. Studying wildlife in cities can also expose urban residents to nature and foster conservation awareness. As such, UWIN has the potential to marshal in a new era of urban wildlife research. Although urban areas may have more homogenous wildlife communities than less developed regions (McKinney 2006), that does not mean that urban communities are identical, lack complex dynamics, or are unworthy of study, especially in light of continuing urban growth and an increasing disconnect between people and nature (Louv 2008). In fact, urban areas represent a new frontier for ecological and social–ecological research, and should be an essential component of wildlife conservation efforts in the future.

Acknowledgements

References

Acuto M, Parnell S, and Seto KC. 2018. Building a global urban science. *Nature Sustainability* **1**: 2–4.

Adams CE and Lindsey KJ. 2010. Urban wildlife management, 2nd edn. Boca Raton, FL: CRC Press.

Aronson MF, La Sorte FA, Nilon CH, *et al*. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *P Roy Soc B-Biol Sci* **281**: 20133330.

Aronson MF, Nilon CH, Lepczyk CA, *et al*. 2016. Hierarchical filters determine community assembly of urban species pools. *Ecology* **97**: 2952–63.

Bateman PW and Fleming PA. 2012. Big city life: carnivores in urban environments. *J Zool* **287**: 1–23.

Beatley T. 2011. Biophilic cities: integrating nature into urban design and planning. Washington, DC: Island Press.

Belair A, Whelan CJ, and Minor ES. 2014. Having our yards and sharing them too: the collective effects of yards on native bird species in an urban landscape. *Ecol Appl* **24**: 2132–43.

Berry MM. 2013. Thinking like a city: grounding social–ecological resilience in an urban land ethic. *Idaho Law Review* **50**: 117–52.

Bjerke T and Østdahl T. 2004. Animal-related attitudes and activities in an urban population. *Anthrozoos* **17**: 109–29.

Borcard D, Gillet F, and Legendre P. 2011. Numerical ecology with R. New York, NY: Springer Science+Business Media.

Borer ET, Harpole WS, Adler PB, *et al.* 2014. Finding generality in ecology: a model for globally distributed experiments. *Methods Ecol Evol* **5**: 65–73.

Braaker S, Ghazoul J, Obrist MK, *et al.* 2014. Habitat connectivity shapes urban arthropod communities: the key role of green roofs. *Ecology* **95**: 1010–21.

Brewer C. 2002. Outreach and partnership programs for conservation education where endangered species conservation and research occur. *Conserv Biol* **16**: 4–6.

Brownell SE, Hekmat-Scafe DS, Singla V, *et al.* 2015. A high-enrollment course-based undergraduate research experience improves student conceptions of scientific thinking and ability to interpret data. *CBE-Life Sci Educ* **14**: art21.

Crooks KR and Soulé ME. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. *Nature* **400**: 563–66.

Dickenson JL, Shirk J, Bonter D, *et al.* 2012. The current state of citizen science as a tool for ecological research and public engagement. *Front Ecol Environ* **10**: 291–97.

Fidino M. 2017. uwinr: an R package for the Urban Wildlife Information Network. www.github.com/mfidino/uwinr. Viewed 4 Oct 2018.

Forman RTT, Sperling D, Bissonette JA, *et al.* 2003. Road ecology: science and solutions. Washington, DC: Island Press.

Gallo T, Fidino M, Lehrer E, *et al.* 2017. Mammal diversity and metacommunity dynamics in urban green spaces: implications for urban wildlife conservation. *Ecol Appl* **27**: 2330–41.

Gehrt SD, Riley SPD, and Cypher BL (Eds). 2010. Urban carnivores: ecology, conflict, and conservation. Baltimore, MD: Johns Hopkins University Press.

Homer CG, Dewitz JA, Yang L, *et al.* 2015. Completion of the 2011 National Land Cover Database for the conterminous United States – representing a decade of land cover change information. *Photogramm Eng Rem S* **81**: 345–54.

Ivan JS and Newkirk ES. 2016. CPW Photo Warehouse: a custom database to facilitate archiving, identifying, summarizing and managing photo data collected from camera traps. *Methods Ecol Evol* **7**: 499–504.

Jones KE, Patel NG, Levy MA, *et al.* 2008. Global trends in emerging infectious diseases. *Nature* **451**: 990–94.

Louv R. 2008. Last child in the woods: saving our children from nature-deficit disorder. New York, NY: Algonquin Books.

Magle SB, Hunt VM, Vernon M, *et al.* 2012. Urban wildlife research: past, present, and future. *Biol Conserv* **155**: 23–32.

Magle SB, Simoni LS, Lehrer EW, *et al.* 2014. Urban predator–prey association: coyote and deer distributions in the Chicago metropolitan area. *Urban Ecosyst* **17**: 875–91.

Marzluff JM, Bowman R, and Donnelly R. 2012. Avian ecology and conservation in an urbanizing world. New York, NY: Springer Science+Business Media.

McDonnell MJ and Pickett STA. 1990. Ecosystem structure and function along urban–rural gradients: an unexploited opportunity for ecology. *Ecology* **71**: 1232–37.

McGranahan G. 2005. An overview of urban environmental burdens at three scales: intra-urban, urban-regional and global. *Int Rev Environ Strategies* **5**: 335–56.

McKinney ML. 2006. Urbanization as a major cause of biotic homogenization. *Biol Conserv* **127**: 247–60.

McKinney ML. 2008. Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosyst* **11**: 161–76.

Miller JR and Hobbs RJ. 2002. Conservation where people live and work. *Conserv Biol* **16**: 330–37.

Mulligan MP, Grant C, Herget J, *et al.* 2015. Partners in Fieldwork: empowering urban high school learners. *Best Practices – Committee for Education and Cultural Action* **4**: 85–94.

Ordeñana MA, Crooks KR, Boydston EE, *et al.* 2010. Effects of urbanization on carnivore species distribution and richness. *J Mammal* **91**: 1322–31.

Ordiz A, Bischof R, and Swenson JE. 2013. Saving large carnivores, but losing the apex predator? *Biol Conserv* **168**: 128–33.

Pacione M. 2009. Urban geography: a global perspective. New York, NY: Routledge.

Rosenzweig ML. 2003. Win–win ecology: how the Earth's species can survive in the midst of human enterprise. New York, NY: Oxford University Press.

Seress G, Lipovits A, Bokony V, *et al.* 2014. Quantifying the urban gradient: a practical method for broad measurements. *Landscape Urban Plan* **131**: 42–50.

Seto KC, Güneralp B, and Hutyra LR. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *P Natl Acad Sci USA* **109**: 16083–88.

Simpson R, Page KR, and De Roure D. 2014. Zooniverse: observing the world's largest citizen science platform. Proceedings of the 23rd International Conference on World Wide Web; 7–11 Apr 2014; Seoul, South Korea. New York, NY: Association for Computing Machinery.

Smith JB, Nielsen CK, and Hellgren EC. 2014. Illinois resident attitudes toward recolonizing large carnivores. *J Wildlife Manage* **78**: 930–43.

Soga M and Gaston K. 2016. Extinction of experience: the loss of human–nature interactions. *Front Ecol Environ* **14**: 94–101.

Soulsbury CD and White PCL. 2016. Human–wildlife interactions in urban areas: a review of conflicts, benefits, and opportunities. *Wildlife Res* **42**: 541–53.

Sullivan BK, Leavitt DJ, and Sullivan KO. 2017. Snake communities on the urban fringe in the Sonoran Desert: influences on species richness and abundance. *Urban Ecosyst* **20**: 199–206.

Threlfall CG, Williams NSG, Hahs AK, *et al.* 2016. Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. *Landscape Urban Plan* **153**: 28–39.

◾ Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2030/suppinfo

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