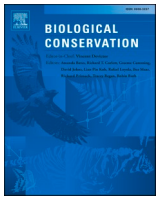
Biological Conservation 261 (2021) 109236

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon



Review

Global trends in urban wildlife ecology and conservation

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ARTICLE INFO

Keywords:
Human dimensions
Urban ecology
Urban green space
Urbanization
Wildlife conservation
Wildlife management

ABSTRACT

As urbanization continues to expand across the globe, urban wildlife research is critical for urban planners and conservation practitioners to create livable cities for both humans and wildlife. In 2012, Magle et al. conducted a foundational review on the status of urban wildlife research. The authors described the status of urban wildlife research as of 2010 and offered suggestions for future advancements in the field. We conducted a systematic review following Magle et al. (2012) to provide a 10-year update on the state of urban wildlife research globally and describe recent advancements in the field. We also conducted a broader literature search to further explore current research trends and continuing research gaps within the urban wildlife field. We found that urban wildlife publications have continued to increase within the last decade. However, the sectors conducting the research and the geographical location of publications stayed relatively the same. Similarly, the predominant taxa studied were mammals and birds across the 2000–2020 decades. After broadening our literature search, we were able to identify a new emphasis on management-related research and research in the fields of disease ecology, social science, and methodological development. Critical knowledge gaps remain, however, as there was still a significant lack of studies on herptiles, arthropods, and fish. Additionally, studies from Africa, South America, and Asia – three of the fastest urbanizing continents – were underrepresented. Our results provide conservation practitioners a summary of emerging topics and recommendations for future research that will contribute to creating healthier and more livable cities for both wildlife and people.

1. Introduction

Human experiences with wildlife are often thought to be limited to more naturally occurring ecosystems. This is primarily due to historic knowledge on wildlife ecology being rooted in more rural areas. The UN now estimates two-thirds of the human population – an estimated 7 billion people – will be living in urban areas by 2050 (United Nations, 2018). This shift to urban environments will continue to change how humans and wildlife interact and reshape what we know about wildlife ecology in human-dominated environments (Aronson et al., 2017).

Urbanization has transformed the way researchers, managers, and city planners approach studying wildlife (Apfelbeck et al., 2020; Magle et al., 2012). Since the 1990s, research on urban wildlife has expanded as cities become viewed as novel ecosystems rather than anthropogenic sinks devoid of nature (Forman, 2016; Gallo et al., 2017; Grimm et al., 2000; Łopucki and Kitowski, 2017). Many entities including government agencies and academic labs have expanded their wildlife conservation focus to include urban wildlife research (Magle et al., 2019; Sexton et al., 2015). A new focus on urban ecosystems – and the wild animals that reside in them – brings new challenges, opportunities, and solutions to integrate human needs with those of wildlife. The range of research topics within the urban wildlife field continues to grow as the importance of understanding how wildlife live, move, and adapt under anthropogenic conditions becomes paramount in the face of larger environmental problems like climate change, landscape fragmentation, and habitat loss (Forman, 2016; McKinney, 2002; Rastandeh et al., 2018). Solving these large-scale problems will require innovative solutions as urban areas increase across the globe. As a relatively new field, urban wildlife research is in-flux, continuing to change and adapt as new questions and issues emerge (Magle et al., 2012). Therefore, it is imperative that practitioners understand the current state of urban wildlife research to identify areas where research is lacking and develop research agendas that inform best practices in management and conservation (Apfelbeck et al., 2020). Looking to past research identifies areas of strength and weakness, reveals potential gaps in current work, and can provide direction for biodiversity conservation within urban

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https://doi.org/10.1016/j.biocon.2021.109236
Received 2 January 2021; Received in revised form 11 June 2021; Accepted 30 June 2021
Available online 10 July 2021

areas.

Magle et al. (2012) conducted a literature review of urban wildlife research from 1971 to 2010. Their review found that urban wildlife research – while limited – was projected to continue increasing past 2010. They also called attention to the need for, and the lack of, integration of various ecological disciplines to answer both fundamental and applied questions within urban wildlife topics. Urban wildlife research is uniquely interdisciplinary, requiring a diverse mix of practitioners, scientists, planners, educators, policy makers, and citizen support (Belaire et al., 2016; Dearborn and Kark, 2010; Schell et al., 2020). To meet the needs of such an interdisciplinary network, it is crucial to understand the status of urban wildlife research within different subjects, contexts, and management areas.

Here we examine the last decade (2011−2020) of urban wildlife research, assess whether the field has addressed research gaps highlighted in Magle et al. (2012), and explore how the field has changed since Magle et al. (2012) first reviewed the literature. To systematically compare the last two decades of urban wildlife research we replicated the literature review methodology used in Magle et al. (2012) for the years 2011–2020. To identify emerging themes in areas outside of the natural sciences, we conducted an additional systematic review that broadened the Magle et al. (2012) search criteria. We used the upward trend data from Magle et al. (2012) to hypothesize that urban wildlife publications have continued to increase between 2011 and 2020, and we further predicted that themes understudied during the previous decade (2000−2010) have emerged as common themes due to the increased demand for understanding urban ecosystems. These up-to-date findings provide researchers and urban wildlife practitioners guidance and clarification on knowledge gaps, best practices, and topics of importance.

2. Materials and methods

To assess the current state of urban wildlife research we took a two-tier approach to conducting a literature review. First, to directly compare results with Magle et al. (2012), we followed the exact methodology outlined in Magle et al. (2012) – an approach that was limited to 16 high impact journals in ecology and wildlife research. Second, we expanded our literature review by conducting an additional review that did not limit our search to select journals. Both approaches are outlined below.

3. Updating Magle et al. (2012) foundational review

3.1. Literature search criteria

Following the methods in Magle et al. (2012), we searched each of the following high impact ecology and wildlife-related journals using Web of Science (WOS) and the term "urban*": *Animal Behavior*, *Behavioral Ecology*, *Behavioral Ecology and Sociobiology American Naturalist, Biological Conservation,* and *Conservation Biology*, *Ecology*, *Ecology Letters*, *Journal of Applied Ecology*, *Journal of Wildlife Management*, *Wildlife Research*, *Wildlife Society Bulletin*, *Landscape Ecology*, *Landscape and Urban Planning, Nature,* and *Science*. We included the asterisks modifier to capture related terms like "suburban," "exurban," and "periurban". We limited our search to January 2011–December 2020. Following Magle et al. (2012) we sorted results based on titles and abstracts to only include original research conducted on urban wildlife, excluding papers such as letters, reviews, theses, dissertations, and papers that did not directly study wildlife (Magle et al., 2012; Roberts et al., 2006).

3.2. Categorization and analysis

Selected publications were grouped into categories based on the journal discipline (animal behavior, conservation, ecology, general science, landscape ecology, and wildlife biology; Table 1), author affiliation (academic, government, non-government organization, or private industry), taxa of study (mammal, bird, arthropod, herptile, fish, or non-taxa); continent of study area, and the scientific topic of each study (animal behavior, population ecology, community ecology, landscape ecology, conservation, human-wildlife conflict, human dimensions, evolution and genetics, or disease ecology).

To assess trends and changes over the last 20 years, we calculated the proportion of urban wildlife publications in each journal and the proportions of studies for each category. We obtained the original data from Magle et al. (2012) and calculated the same proportions from these data for 2000–2010. We found one error that changed the total number of papers in the 2001–2010 dataset from 429 to 431. This error was verified by the authors and the corrected value was used in our analysis. To quantify changes over time, we compared proportions from 2001 to 2010 with the proportions from 2011 to 2020 using chi-squared tests for comparing two proportions (also known as a z-test) in R ver. 3.6 (R Core Team, 2013; Kim, 2017). In some categories, data from Magle et al. (2012) were aggregated for 1971–2010 and we were unable to isolate the results for 2000–2010. In these cases, we only report the percent change between the two datasets.

Table 1
A comparison of the total number of publications and the total number of urban wildlife publications between 1971 and 2010 and 2011–2020 in each of the 16 high-impact ecology and wildlife-related journals reviewed.

		1971–2010			2010–2020			
Journal discipline	Journal	Total	Urban wildlife	% Total	Total	Urban wildlife	% Total	% Change
Anim Behav	Anim Behav	9479	10	0.11	3172	25	0.8	−627
	Behav Ecol	2211	11	0.5	1952	52	2.6	420
	Behav Ecol Sociobio	3926	7	0.18	1980	20	1.0	455
Conserv	Am Nat	5456	5	0.09	1754	5	0.3	233
	Biol Conserv	5237	117	2.23	3876	75	1.9	−13
	Conserv Biol	3863	56	1.45	1758	17	0.9	−37
Ecology	Ecol	9401	18	0.19	3262	9	0.3	57
	Ecol Lett	1524	1	0.07	1780	3	0.1	43
	J Appl Ecol	3726	16	0.43	2074	34	1.6	272
Gen Science	Nature	121,290	1	<0.01	8568	3	0.04	300
	Science	90,350	1	<0.01	7415	5	0.07	600
Land Ecol	Land Urban Plan	2305	85	3.69	1935	116	5.9	59
	Land Ecol	1301	42	3.23	1542	56	3.6	12
Wildlife Biol	J Wildlife Mgmt	6231	77	1.24	1751	38	2.1	75
	Wildlife Res	1405	58	4.13	766	41	5.3	29
	Wildlife Soc B	2931	66	2.25	1014	33	3.2	45

4. Broadened literature search

4.1. Literature search criteria

We conducted an additional review using a broader approach. We searched WOS and Google Scholar using the search term "urban* wildlife". An asterisk modifier was again applied to include related terms like "exurban", "suburban", and "periurban" in the search results. We limited our search to the years 2011–2020, but included all scientific journals indexed by WOS and Google Scholar. Google Scholar limits article downloads to the first 1000 results, regardless of the number of results returned. Therefore, we limited our Google Scholar results to the first 1000 articles returned by Google Scholar. We did not limit our journal selection by selecting topic specific journals, or only high impact journals to objectively broaden our search. We sorted results based on titles and abstracts to only include original research conducted on urban wildlife and excluded letters, reviews, dissertations, and papers that did not directly study wildlife.

4.2. Classification and analysis

We classified our results in a similar way with some additions to each category to accommodate the wider breadth of included journals. "Crustacea" was added to the taxa category, "environmental," "human dimensions," "veterinary," and "zoology," were added to the journal disciplines based on the journal titles. Research topics, "social science" and "spatial ecology" were added due to the number of journal articles reflecting these topics. Taxa were then classified further into subgroups (e.g., bird to raptor, mammal to carnivore, arthropod to pollinator, herptile to reptile), or into a subtopic if study fell into the "non-taxa" category (e.g., methods, human dimensions). Of these, the subgroup, discipline, and topic with the highest number of publications were classified further to species or subject to examine more fine scale trends and research gaps (Table 1). Finally, we classified all papers as either "fundamental" or "applied" research based on reading abstracts and discussions sections. Any paper that was founded or built on current knowledge of a subject to improve current theories, but did not have direct or immediate problem-solving application, was classified as fundamental research. Papers classified as applied research included a direct call to action to make changes to policy, urban planning, management, conservation, current methods, or solve immediate problems.

5. Results

5.1. Updating Magle et al. (2012) foundational review

Using the search term "urban*" within the 16 selected journals yielded 2172 results between January 2011–December 2020. Of these, 532 were determined to fit our inclusion criteria. Of the 1640 publications excluded from our data, 93.10% (1527/1640) did not research wildlife and 11.46% (188/1640) were not original research articles. The total number of urban wildlife publications from these journals continued to increase between 2011 and 2020 (0.02% per year), yet at a slightly lower rate than the previous decade (0.06% per year; Fig. 1).

Journals that typically publish behavior studies saw a significant increase within the last decade (6.5% to 18.2%; $\chi^2 = 5.54$, $p = 0.018$, df = 1). Conservation-related journals significantly decreased in percentage of overall urban wildlife publications, dropping from 32.8% in 2001–2010 to 18.2% in 2011–2020 ($\chi^2 = 3.79$, $p = 0.05$, df = 1). Additionally, publications in landscape journals continued to rise but had a substantial decrease in urban wildlife publications between 2013 and 2015 (Fig. 2). Regarding specific journals, Landscape and Urban Planning (5.9%), Wildlife Research (5.3%), and Landscape Ecology (3.6%) continued to produce the highest number of urban wildlife publications of the 16 selected journals (Table 1). Science (600%; 1 to 5) and Behavioral Ecology and Sociobiology (455%; 7 to 20) had the highest increase of urban wildlife publications compared to the previous analysis, followed by Behavioral Ecology (420%; 11 to 52; Table 1). Although the overall percentages remain low, both Nature (0.04%) and Science (0.07%) experienced increases of urban wildlife publications within the last decade.

5.2. Author affiliation and geographic area

Overall, between 1971 and 2020, 80.81% of all urban wildlife publications from the 16 selected journals had first author affiliations with academic institutions (Table 2). While not statistically significant, academic affiliations increased from 75.75% of total publications in 2001–2010 to 88.90% in 2011–2020. Government institution affiliated authorships in urban wildlife publications decreased from 13.28% in 2001–2010 to 7.10% in 2011–2020, causing an overall total decrease in government affiliated publications from 1971 to 2020 as reported in Magle et al. (2012); −46%). The overall percentage of NGO affiliated authors significantly decreased within the last two decades from 11.18% in 2001–2010 to 3.42% in 2011–2020 ($\chi^2 = 4.12$, $p = 0.0427$, df = 1; Table 3). Private industry urban wildlife publications remain the lowest overall first author affiliation (0.45%, Table 2). Geographically, we

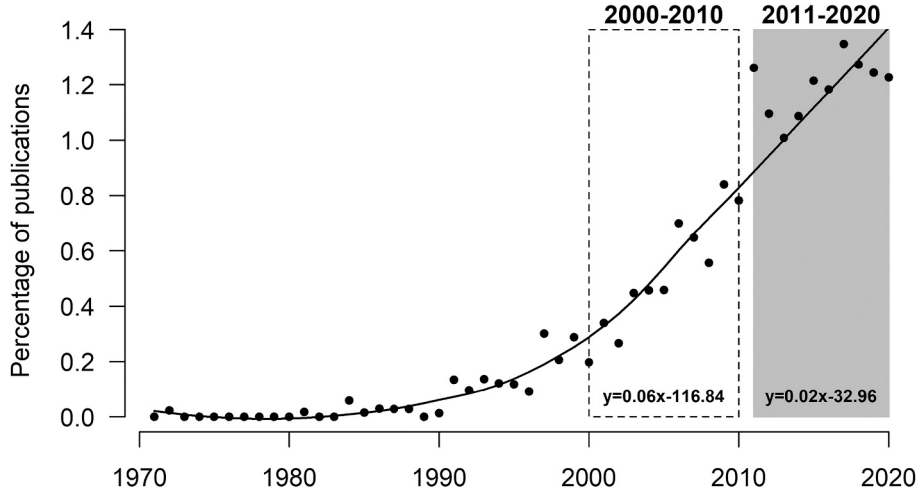

Fig. 1. Percentage of urban wildlife publications from 16 selected journals from 1971 to 2020.

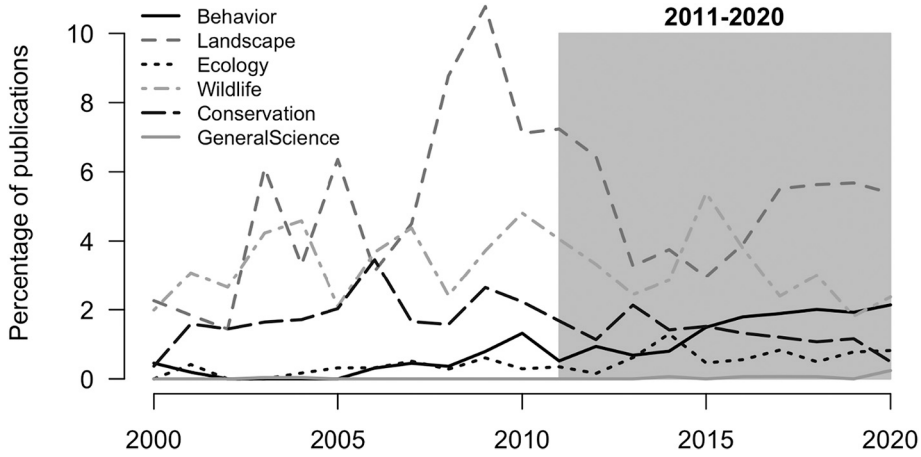

Fig. 2. Percentage of urban wildlife publications from 2000 to 2020 based on field of study in the 16 selected journals reviewed. Grey polygon indicates the period of the most recent decade reviewed.

Table 2
Sector of first author affiliations on urban wildlife publications from 16 selected journals between 1971 and 2020 expressed as percentages.

Decade	Urban wildlife publications	% academic	% government	% NGO	% private
1971–1980	1	100	0	0	0
1981–1990	13	69.23	23.08	0	7.69
1991–2000	128	66.41	20.31	11.72	1.56
2001–2010	431	75.75	13.28	11.18	0.23
2011–2020	532	88.90	7.10	3.42	0.50
Total	1105	80.81	11.22	7.33	0.45

found that North America had the most urban wildlife publications within the selected journals (41.7%; $n = 222$) followed by Europe (29.3%; $n = 156$), and Australia (16.1%; $n = 86$), following the same trend identified in Magle et al. (2012). Further, consistent with Magle et al. (2012), Asia (6.2%; $n = 33$), South America (3.9%; $n = 21$), and Africa (2.6%; $n = 14$) remain the lowest publishing continents on urban wildlife research within the 16 selected journals.

5.3. Scientific topic

The most frequently represented scientific topics in urban wildlife publications from 2011 to 2020 were animal behavior (23.1%; 123/532), conservation (13.9%; 74/532), and wildlife management (13.1%; 70/532). Other topics represented from 2011 to 2020 were landscape ecology (12.4%; 66/532), population ecology (12.0%; 64/532), community ecology (9.3%; 50/532), human-wildlife conflict (5.4%; 29/532), disease ecology (5.4%; 29/532), evolution and genetics (3.3%; 19/532) and human dimensions (2.2%;12/532). Notably, topics of disease ecology had an 80% increase in publications over just a ten-year period (5.4% of urban wildlife publications in 2011–2020 compared to 2.6% over four decades – 1971-2010). Similarly, topics in evolution and genetics had a 37% increase over the same time periods from 2.4% between 1971 and 2010 to 3.3% in 2011–2020.

5.4. Taxa

Urban wildlife publications in the 16 selected journals remained consistent with Magle et al. (2012) in terms of focusing on specific taxa. Studies were conducted predominantly on birds (41.7%) and mammals (30%; Fig. 3). Fish were the least studied taxa representing only 1.3% of all publications from 2011 to 2020 (7/532). We found no significant change in taxa studied between 2001 and 2010 and 2011–2020 (Table 3). Although not statistically significant we did see a notable increase in urban arthropod studies and decrease in urban mammal studies between the 2000–2020 decades (Fig. 3).

6. Broadened literature search

Our broadened search using a combination of WOS ($n = 532$) and Google Scholar ($n = 305$) yielded 794 results. Within these results, 203

Table 3
Chi-squared results comparing percentage of urban wildlife publications from 2000 to 2010 to 2011–2020 by first author affiliation, geographic location of the study, and main taxa of study. Bold *p*-value indicates a significant change.

	Category	2000–2010	2011–2020	X^2	p-Value	df
Author affiliation	Academia	75.75	88.90	0.9241	0.3364	1
	Government	13.28	7.10	1.4474	0.2291	1
	NGO	11.18	3.42	3.7855	**0.0517**	1
	Private	0.23	0.50	0.1649	0.6846	1
Geographic location	N. America	51.0	41.7	1.0194	0.3127	1
	Europe	20.7	29.3	1.6398	0.2004	1
	Australia	18.4	16.1	0.6566	0.1976	1
	Asia	6.8	6.20	0.05	0.8231	1
	S. America	3.7	3.90	0.0116	0.9139	1
	Africa	2.8	2.60	1	0	1
Taxa	Arthropod	11.86	17.29	1.0115	0.3145	1
	Bird	41.76	41.72	1.9166	0.9965	1
	Fish	4.17	1.31	1.5291	0.2162	1
	Herptile	10.2	7.33	0.4759	0.4903	1
	Mammal	38.0	30.0	0.9411	0.3321	1
	Non-Taxa	4.17	2.25	0.57302	0.4491	1

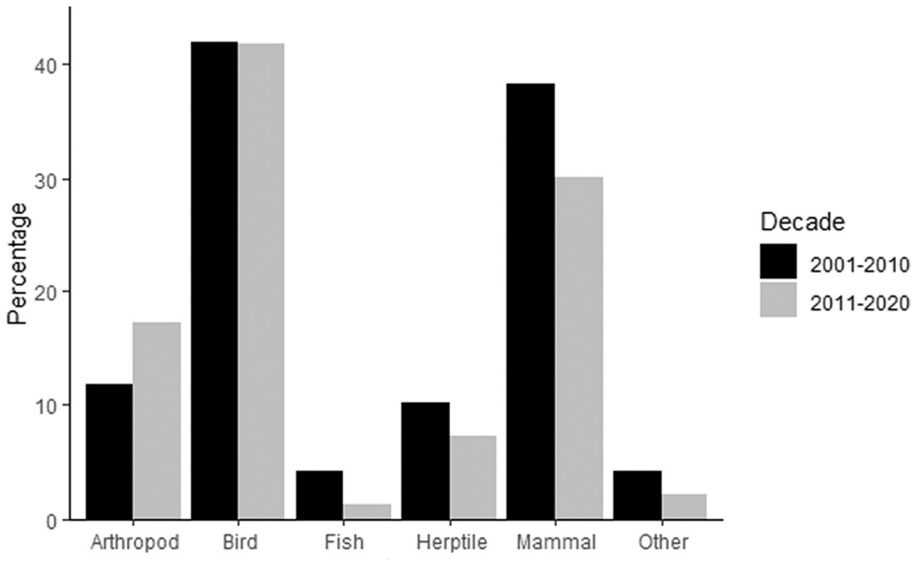

Fig. 3. Urban wildlife publications categorized by taxa studied and their percentage of the overall number of urban wildlife studies in the selected 16 ecology and wildlife journals reviewed.

publications were duplicate publications from both search engines, leaving us with a total of 634 urban wildlife studies from 2011 to 2020. Within this search, 214 journals were identified and categorized by discipline, as compared to the 16 journals used in Magle et al. (2012) methods. Disciplines in urban wildlife research included Wildlife Biology (22.9%, $n = 145$), Landscape Ecology (18.9%, $n = 120$), Ecology (10.6%, $n = 67$), Conservation (10.1%, $n = 64$), General Science (8.5%, $n = 54$), Environmental Science (8.5%, n = 54), Veterinary (7.1%, $n = 45$), Human Dimensions (6.6%, $n = 42$), Zoology (4.6%, $n = 29$), and Behavior (2.2%, n = 14).

6.1. Scientific topic

Within the broader literature search, urban wildlife research topics consisted of management (19.4%, $n = 123$), disease ecology (12.3%, $n = 77$), social science (10.7%, $n = 68$), behavior (10.2%, $n = 65$), human/wildlife conflict (10.1%, n = 64), population ecology (9.9%, $n = 63$), landscape ecology (7.9%, $n = 50$), conservation (6.6%, n = 42), community ecology (5.0%, $n = 32$), spatial ecology (4.1%, $n = 26$), and evolution/genetics (3.8%, $n = 24$). Most notably, social sciences had the highest publication percentages within the 2020 year (19.2%, $n = 10$).

6.2. Main taxa and subgroups

Of the 634 urban wildlife publications, mammal studies represented 46.4% of the total publications ($n = 294$), birds 26.5% ($n = 168$), non-taxa studies 16.4% ($n = 104$), herptiles 4.6% (n = 29), arthropods 4.1% (n = 26), multiple taxa studies 1.6% ($n = 10$), fish 0.3% (n = 2), and crustaceans 0.1% (n = 1). We further categorized each of these urban wildlife taxa into subgroups (Table 1). The top three groups within mammal research were carnivores (31.6%, $n = 93$), rodents (17.3%, $n = 51$), and invasive species (12.6%, $n = 37$). Of carnivores, coyotes (*Canis latrans*, 36.5%, $n = 34$) and red foxes (*Vulpes vulpes*, 18.3%, $n = 17$) made up the most studied species. Rodents were predominantly represented by studies focused equally on rat species as well as studies encompassing multiple rodent species, (*Rodentia*, 23.5%, $n = 12$). Of the studies investigating multiple rodent species, 50% ($n = 6$) studied rat and mouse species (*Muridae*). Invasive mammal species were predominantly represented by free-roaming domesticated cats (*Felis catus*, 56.8%, $n = 21$), and feral swine (*Sus scrofa*, 30.0%, $n = 11$). Birds were most represented by subclasses songbirds, raptors, and aquatic species. Of these, songbirds were most studied across multiple groups (71.8%, n = 51/71). Raptors were most represented by owls (*Strigiformes*, 26.6%, $n = 8/30$) and Cooper's hawks (*Accipiter cooperii*, 23.3%, $n = 7/30$), and of aquatic birds, ibises were the most represented (*Threskiornithinae,* 26.9%, n = 7/26). Lizards were the most studied herptile (*Lacertilia*, 34.4%, n = 10/29) and pollinators were the highest studied arthropod class (60.0%, $n = 15/26$). Of pollinators, bee species were the most researched (*Anthophila*, 40%, n = 6/15) with butterflies following closely behind (*Rhopalocera*, 33.3%, n = 5/15). The most represented subclass of the category "non-taxa" were papers researching urban wildlife methodologies. Of these, methodologies in education (40.2%, $n = 39/97$), development/planning (23.7%, $n = 23/97$), and statistical modeling (12.4%, n = 12/97) were the most prevalent.

When comparing urban wildlife taxa and research topics, mammals were most studied for management (20.7%, $n = 61/294$), disease ecology (14.3%, $n = 42/294$), and human/wildlife conflict research (14.3%, n = 42/294). Birds were most studied for landscape ecology (16.1%, $n = 27/168$) and disease ecology (14.3%, $n = 24/168$). The non-taxa category contained studies most focused on the topics of social sciences (37.7%, $n = 43/114$) and management (35.1%, $n = 40/114$). Herptiles were most represented in studies on population ecology (27/6%, $n = 8/29$). Arthropods were most represented in studies on conservation (30.7%, n = 8/26). All fish studies (n = 2) were examples of disease ecology research, and the single urban crustacean study was focused on population ecology.

6.3. Fundamental vs. applied research

Of all 634 urban wildlife studies 66.1% were applied ($n = 419$) and 33.9% ($n = 215$) were considered fundamental or foundational research. Fish had the highest percentage of applied research studies (100%, n = 2) followed by herptiles (73.1%, $n = 19/26$), and birds had the lowest percentage of applied research papers (55.9%, $n = 81$). Papers within the "non-taxa" category had a 93.2% applied research rate due to the majority ($n = 97$) being methods papers.

7. Discussion

Urban wildlife publications have continued increasing within the last decade, indicating urban wildlife research remains an important and expanding field of wildlife and conservation science. Our results indicate several emerging trends within urban wildlife research. While updating Magle et al. (2012), we found behavior, conservation, and wildlife

management were the leading topics during the 2011–2020 decade. However, within our broadened search we found management, disease ecology, and social sciences to be the most studied topics. We also found that applied studies, including papers on research methods, made up a significant percentage of urban wildlife research within the last decade. Trends remaining the same between decades included a geographical bias to North America, and mammals and birds leading research by taxa. Recognizing understudied areas within urban wildlife research can aid researchers in identifying where more information is needed to manage and conserve urban wildlife.

The frequency of published disease ecology research doubled between 2000 and 2020. After we broadened our literature search to include more journals, disease ecology became the second most studied topic behind management. These results are a likely indication that urban wildlife research is trending toward a more interdisciplinary field as veterinarians, health care professionals, and managers seek to identify possible zoonotic spillover risks in cities and assess linkages between human and wildlife health (Himsworth et al., 2014; Leibler et al., 2018). This trend aligns with the recent increase in the adoption of a "One Health" approach, wherein human health and ecological health are considered one, versus separate issues (Destoumieux-Garzón et al., 2018). Rapid urbanization impacts surrounding environments and the wildlife residing within them, creating novel opportunities for zoonotic spillovers that would otherwise not be possible. This has been the case with the Ebola, Nipah, and SARS outbreaks within the last decade, as well as the 2020 pandemic resulting from potential spillover of the novel COVID-19 virus (Mackenzie and Smith, 2020). The need for more advanced zoonotic disease research in urban areas will remain paramount to aid in predicting and modeling emergent vectors and geographic hotspots at risk for zoonotic spillover (Santiago-Alarcon and MacGregor-Fors, 2020).

Methods papers were also a new and prominent addition within our broadened literature search. Educational techniques were the most common subtopic within methods papers. These included urban ecology school program planning, community gardening and ecology program planning, and sociological studies on efficacy of urban wildlife outreach programs (Larson et al., 2016; Patterson et al., 2017; Wieczorek Hudenko, 2012). These results demonstrate a greater effort to include the public in decision making processes, scientific studies, and a new emphasis on the importance of educating the public about urban wildlife. These findings are encouraging, as a continued focus on education can help mitigate common problematic interactions between humans and wildlife such as wildlife feeding, vehicle collisions, and direct conflicts such as damage management (Awasthy et al., 2012; Hobbs and White, 2016; Hunold, 2020).

An additional emergent topic within our broad review was social science. Social sciences represented 10.7% of all urban wildlife publications between 2010 and 2020. Papers within this topic include research on urban residents' perceptions of nature (Jacobs et al., 2012; Wieczorek Hudenko, 2012), surveys on public opinions regarding wildlife management (Jacobs et al., 2014; van Eeden et al., 2019), and how social and socioeconomic identities play a role in acceptance or rejection of wildlife management practices (Gledhill and James, 2012; Farmer et al., 2013; Palamar et al., 2013). These topics align with a growing focus on the importance of understanding coupled human-natural systems and urban socio-ecological systems, including linking biodiversity to historical urban development and social inequalities (Schell et al., 2020; Ackley et al., 2015; Liu et al., 2007; Magle et al., 2016). Additionally, our assessment of applied versus fundamental research reveals that most urban wildlife research conducted within the last decade is applied, likely due to the proximity of which humans and wildlife live in cities and the need to develop strategies to coexist with wildlife. Humans and wildlife share the same habitat. Thus, management decisions regarding wildlife have a direct impact on humans. Therefore, an understanding of these ripple effects has begun gaining prominence within the literature. Fundamental research on urban wildlife may be less prevalent due to many urban species being inherently common and an existing strong understanding of the life history and biology of these species. Understanding the interconnected relationships between people and wildlife will be central to creating spaces where wild animals and people can peacefully coexist (Liu et al., 2007).

We also found shortcomings where urban wildlife research has not improved over the last decade. Academia continues to lead in urban wildlife research publications. This is likely due to major funding sources in developed countries, such as governmental funding, not allocating substantial funds toward urban wildlife research. Despite most of the human population residing in cities, research funding is still predominantly funneled into rural ecosystem projects (Adams, 2005). Additionally, we found that North America, Europe, and Australia continue to lead publications in urban wildlife studies. This leaves a significant knowledge gap in urban wildlife studies in Asian, South American, and African countries – all rapidly urbanizing continents (UN, 2018). Complex dynamics of politics, economics, and inequality likely lead to a lack of overall urban ecology research within countries on these continents (Freire, 2006). Many of these areas contain unique and biodiverse species. For example, Sub-Saharan Africa is cited as the most rapidly urbanizing area of the globe, with 40% of land classified as urban in 2015. This area is also home to irreplaceable bird biodiversity to which the region has been designated a global conservation priority (Brooks et al., 2006; DiMarco et al., 2016). The rate of urbanization in these data deficient regions, coupled with the number of endemic species, reveal a critical knowledge gap. Expanding research funding in these biodiverse areas would significantly aid global wildlife conservation, especially in growing international cities.

Finally, regarding specific taxa, we found that herptiles, arthropods, and fish remained the least studied taxa groups over the last two decades. While studies of urban mammals and birds are invaluable to conservation, increasing research on other taxa groups will be crucial for future biodiversity conservation. According to the International Union for Conservation of Nature (IUCN), 39.2% of all known amphibian species, 23.9% of all known reptile species, and 27.0% of all known arthropod species are considered 'vulnerable' to extinction (IUCN, 2020). Urbanization and housing development are the number one cause of concern for population declines across all three of these taxa (IUCN, 2020). Focusing research on the ecology of these taxa in urban areas will contribute to global conservation efforts. Fish species also continued to be overlooked within the field of urban wildlife research (Fig. 3). Freshwater fish are often used as bioindicators of water quality, stream health, and early indicators of possible chemical contamination in freshwater resources (Requea et al.,2017). Therefore, focused research and monitoring of urban fish populations could provide insight into effective water management in urban ecosystems. It is unclear why there is such an overall lack of herptile, arthropod, and fish research within urban systems. Perhaps larger and more charismatic wildlife that are often associated with human-wildlife conflict receive the bulk of funding and research resources (Brooke et al., 2014). However, expanding the taxa studied to encompass a broader range of species can assist our overall understanding of how species interact in urban settings, and how urban ecosystems function.

8. Conclusions

Urban wildlife management and conservation remains a young field of research, and our results highlight a continued steady increase in urban wildlife research, as well as new emerging topics. However, significant knowledge gaps can still be found. The field would benefit from more studies of herpetofauna, arthropods and fish, and there is still a need for increased urban wildlife research in the rapidly urbanizing global South. We found that academics continue to make up a substantial portion of first authors within the literature, leaving a significant gap of valuable research contributions from other career fields –

particularly government agencies and NGO's. Although we report remaining research gaps, we also found advancements in urban wildlife research. We identified social sciences and disease ecology as emerging priority topics, and many papers on new research methodologies, particularly in educational research. Urban wildlife management and conservation will benefit from continuing to expand the breadth of interdisciplinary research topics and including more topics outside of the natural sciences, such as sociology, education, outreach, urban planning, policy, and economics.

As urbanization continues to expand across the globe, urban wildlife ecology remains a pertinent and growing field of study within the sciences. As we begin to better understand how to manage and conserve biodiversity within cities, new questions will continue to emerge. Making room for interdisciplinary and diverse players within the field will help solve global conservation issues. A continued expansion of urban wildlife research will allow for more resilient urban ecosystems making cities more livable for both humans and wildlife.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2021.109236.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to acknowledge that the research conducted for this literature review took place during the global COVID-19 pandemic. As of the last revision of this manuscript, 2.93 million people had lost their lives – many from our conservation community. We hold their families, friends, and colleagues in our thoughts, and dedicate this manuscript to those we have lost. We would also like to thank the operations, facilities, and administrative staff at George Mason University as their work behind the scenes is vital to our research. Finally, we would like to thank two anonymous reviewers whose suggestions substantially improved an earlier version of this manuscript.

References

Ackley, J.W., Wu, J., Angilletta Jr., M.J., Myint, S.W., Sullivan, B., 2015. Rich lizards: how affluence and land cover influence the diversity and abundance of desert reptiles persisting in an urban landscape. Biol. Conserv. 182, 87–92.
Adams, L.W., 2005. Urban wildlife ecology and conservation: a brief history of the discipline. Urban Ecosyst. 8 (2), 139–156.
Apfelbeck, B., Snep, R.P., Hauck, T.E., Ferguson, J., Holy, M., Jakoby, C., MacIvor, J.S., Schär, L., Taylor, M., Weisser, W.W., 2020. Designing wildlife-inclusive cities that support human-animal co-existence. Landsc. Urban Plan. 200.
Aronson, M.F., Lepczyk, C.A., Evans, K.L., Goddard, M.A., Lerman, S.B., MacIvor, J.S., Nilon, C.H., Vargo, T., 2017. Biodiversity in the city: key challenges for urban green space management. Front. Ecol. Environ. 15 (4).
Awasthy, M., Popovic, A.Z., Linklater, W.L., 2012. Experience in local urban wildlife research enhances a conservation education programme with school children. Pac. Conserv. Biol. 18 (1), 41–46.
Belaire, J.A., Westphal, L.M., Minor, E.S., 2016. Different social drivers, including perceptions of urban wildlife, explain the ecological resources in residential landscapes. Landsc. Ecol. 31 (2), 401–413.
Brooke, Z.M., Bielby, J., Nambiar, K., Carbone, C., 2014. Correlates of research effort in carnivores: body size, range size and diet matter. PLoS One 9 (4), e93195.
Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A., Gerlach, J., Hoffmann, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S., 2006. Global biodiversity conservation priorities. Science 313.
Dearborn, D.C., Kark, S., 2010. Motivations for conserving urban biodiversity. Conserv. Biol. 24 (2), 432–440.
Destoumieux-Garzón, D., Mavingui, P., Boëtsch, G., Boissier, J., Darriet, F., Duboz, P., Fritsch, C., Giraudoux, P., Le Roux, F., Morand, S., Paillard, C., 2018. The one health concept: 10 years old and a long road ahead. Front. Vet. Sci. (5), 14.
DiMarco, M., Brooks, T., Cuttelod, A., Fishpool, L.D., Rondinini, C., Smith, R.J., Bennun, L., Butchart, S.H., Ferrier, S., Foppen, R.P., Joppa, L., 2016. Quantifying the relative irreplaceability of important bird and biodiversity areas. Conserv. Biol. 30 (2).
Farmer, M.C., Wallace, M.C., Shiroya, M., 2013. Bird diversity indicates ecological value in urban home prices. Urban Ecosyst. 16 (1), 131–144.
Forman, R.T., 2016. Urban ecology principles: are urban ecology and natural area ecology really different? Landsc. Ecol. 31 (8), 1653–1662.
Freire, M., 2006. Urban planning: Challenges in developing countries. In: International Congress on Human Development (Madrid).
Gallo, T., Fidino, M., Lehrer, E.W., Magle, S.B., 2017. Mammal diversity and metacommunity dynamics in urban green spaces: implications for urban wildlife conservation. Ecol. Appl. 27 (8), 2330–2341.
Gledhill, D.G., James, P., 2012. Socio-economic variables as indicators of pond conservation value in an urban landscape. Urban Ecosyst. 15 (4), 849–861.
Grimm, N.B., Grove, J.G., Pickett, S.T., Redman, C.L., 2000. Integrated approaches to long-term studies of urban ecological systems: urban ecological systems present multiple challenges to ecologists—pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory. BioScience 50 (7), 571–584.
Himsworth, C.G., Jardine, C.M., Parsons, K.L., Feng, A.Y., Patrick, D.M., 2014. The characteristics of wild rat (Rattus spp.) populations from an inner-city neighborhood with a focus on factors critical to the understanding of rat-associated zoonoses. PLoS One 9 (3), e91654.
Hobbs, S.J., White, P.C., 2016. Achieving positive social outcomes through participatory urban wildlife conservation projects. Wildl. Res. 42 (7), 607–617.
Hunold, C., 2020. Urban greening and human-wildlife relations in Philadelphia: from animal control to multispecies coexistence? Environ. Values 29 (1), 67–87.
IUCN 2020. The IUCN red list of threatened species. Version 2020-2. https://www.iucnredlist.org. Downloaded on 09 July 2020.
Jacobs, M.H., Vaske, J.J., Roemer, J.M., 2012. Toward a mental systems approach to human relationships with wildlife: the role of emotional dispositions. Hum. Dimens. Wildl. 17 (1), 4–15.
Jacobs, M.H., Vaske, J.J., Sijtsma, M.T., 2014. Predictive potential of wildlife value orientations for acceptability of management interventions. J. Nat. Conserv. 22 (4), 377–383.
Kim, H.Y., 2017. Statistical notes for clinical researchers: chi-squared test and Fisher's exact test. Restorative Dent. Endodontics 42 (2), 152.
Larson, L.R., Cooper, C.B., Hauber, M.E., 2016. Emotions as drivers of wildlife stewardship behavior: examining citizen science nest monitors' responses to invasive house sparrows. Hum. Dimens. Wildl. 21 (1), 18–33.
Leibler, J.H., Zakhour, C.M., Gadhoke, P., Gaeta, J.M., 2016. Zoonotic and vector-borne infections among urban homeless and marginalized people in the United States and Europe, 1990–2014. Vector Borne Zoonotic Dis. 16 (7), 435–444.
Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., 2007. Complexity of coupled human and natural systems. Science 317 (5844), 1513–1516.
Łopucki, R., Kitowski, I., 2017. How small cities affect the biodiversity of ground-dwelling mammals and the relevance of this knowledge in planning urban land expansion in terms of urban wildlife. Urban Ecosyst. 20 (4), 933–943.
Mackenzie, J.S., Smith, D.W., 2020. COVID-19—a novel zoonotic disease: a review of the disease, the virus, and public health measures. Asia Pac. J. Public Health 32 (4), 145–153.
Magle, S.B., Hunt, V.M., Vernon, M., Crooks, K.R., 2012. Urban wildlife research: past, present, and future. Biol. Conserv. 155, 23–32.
Magle, S.B., Lehrer, E.W., Fidino, M., 2016. Urban mesopredator distribution: examining the relative effects of landscape and socioeconomic factors. Anim. Conserv. 19 (2), 163–175.
Magle, S.B., Fidino, M., Lehrer, E.W., Gallo, T., Mulligan, M.P., Ríos, M.J., Ahlers, A.A., Angstmann, J., Belaire, A., Dugelby, B., Gramza, A., 2019. Advancing urban wildlife research through a multi-city collaboration. Front. Ecol. Environ. 17 (4).
McKinney, M.L., 2002. Urbanization, biodiversity, and conservation: the impacts of urbanization on native species are poorly studied but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. Bioscience 52 (10), 883–890.
Palamar, M.B., Peterson, M.N., Deperno, C.S., Correa, M.T., 2013. Assessing rabies knowledge and perceptions among ethnic minorities in Greensboro, North Carolina. J. Wildl. Manag. 77 (7), 1321–1326.
Patterson, L., Kalle, R., Downs, C., 2017. A citizen science survey: perceptions and attitudes of urban residents towards vervet monkeys. Urban Ecosyst. 20 (3), 617–628.
R Core Team, 2013. R: A language and environment for tatistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL. https://www.R-project.org/.
Rastandeh, A., Zari, M.P., Brown, D.K., 2018. Components of landscape pattern and urban biodiversity in an era of climate change: a global survey of expert knowledge. Urban Ecosyst. 21 (5), 903–920.
Roberts, P.D., Stewart, G.B., Pullin, A.S., 2006. Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. Biol. Conserv. 132, 409–423.
Santiago-Alarcon, D., MacGregor-Fors, I., 2020. Cities and pandemics: urban areas are ground zero for the transmission of emerging human infectious diseases. J. Urban Ecol. 6 (1).
Schell, C. J., Dyson, K., Fuentes, T. L., Des Roches, S., Harris, N. C., Miller, D. S., Woelfle-Erskine, C.A. & Lambert, M. R. (2020). The ecological and evolutionary consequences of systemic racism in urban environments. Science, 369(6510).
Sexton, N.R., Ross-Winslow, D., Pradines, M., Dietsch, A.M., 2015. The urban wildlife conservation program: building a broader conservation community. Cities Environ. (CATE) 8 (1), 3.

United Nations, Department of Economic and Social Affairs, Population Division, 2018. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). United Nations, New York.

van Eeden, L.M., Newsome, T.M., Crowther, M.S., Dickman, C.R., Bruskotter, J., 2019. Social identity shapes support for management of wildlife and pests. Biol. Conserv. 231, 167–173.

Wieczorek Hudenko, H., 2012. Exploring the influence of emotion on human decision making in human–wildlife conflict. Hum. Dimens. Wildl. 17 (1), 16–28.