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City-size bias in knowledge on the effects of urban nature on people and biodiversity

Dave Kendal[1], Monika Egerer[2], Jason A Byrne[1], Penelope J Jones[3], Pauline Marsh[4], Caragh G Threlfall[5,6], Gabriella Allegretto[1], Haylee Kaplan[1], Hanh K D Nguyen[1], Sue Pearson[7], Abigail Wright[1] and Emily J Flies[8]

[1] School of Technology, Environments and Design, University of Tasmania, Hobart, TAS 7000, Australia
[2] Department of Ecology, Ecosystem Science/Plant Ecology, Technische Universität Berlin, Rothenburgstr. 12, 12165 Berlin, Germany
[3] Menzies Institute for Medical Research, University of Tasmania, Hobart, TAS 7000, Australia
[4] Centre for Rural Health, University of Tasmania, Hobart, TAS 7000, Australia
[5] School of Life and Environmental Sciences, The University of Sydney, Sydney, NSW 2006, Australia
[6] School of Ecosystem and Forest Sciences, The University of Melbourne, Parkville, VIC 3010, Australia
[7] School of Medicine, University of Tasmania, Hobart, 7000 TAS, Australia
[8] School of Natural Sciences, University of Tasmania, Hobart, 7000 TAS, Australia

E-mail: **dave.kendal@utas.edu.au**

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Abstract

The evidence base for the benefits of urban nature for people and biodiversity is strong. However, cities are diverse and the social and environmental contexts of cities are likely to influence the observed effects of urban nature, and the application of evidence to differing contexts. To explore biases in the evidence base for the effects of urban nature, we text-matched city names in the abstracts and affiliations of 14 786 journal articles, from separate searches for articles on urban biodiversity, the health and wellbeing impacts of urban nature, and on urban ecosystem services. City names were found in 51% of article abstracts and 92% of affiliations. Most large cities were studied many times over, while only a small proportion of small cities were studied once or twice. Almost half the cities studied also had an author with an affiliation from that city. Most studies were from large developed cities, with relatively few studies from Africa and South America in particular. These biases mean the evidence base for the effects of urban nature on people and on biodiversity does not adequately represent the lived experience of the 41% of the world's urban population who live in small cities, nor the residents of the many rapidly urbanising areas of the developing world. Care should be taken when extrapolating research findings from large global cities to smaller cities and cities in the developing world. Future research should encourage research design focussed on answering research questions rather than city selection by convenience, disentangle the role of city size from measures of urban intensity (such as population density or impervious surface cover), avoid gross urban-rural dualisms, and better contextualise existing research across social and environmental contexts.

1. Introduction

Urban nature underpins the health and wellbeing of human and non-human life in settlements around the world (Ives *et al* 2017, Nilon *et al* 2017, Zhang *et al* 2020). Global policies advocating universal access to green space (such as the United Nation's Sustainable Development Goals and the New Urban Agenda (UN Habitat 2016)) and local policies promoting urban forests and public green spaces are supported by thousands of studies demonstrating the dependence of biodiversity, ecosystem services and human health benefits on urban nature. Yet what if this evidence base is skewed? A better understanding of biases in the literature is needed to identify new research priorities and to generalise existing literature to particular local contexts.

A substantial and growing body of evidence suggests that urban nature can benefit human health and wellbeing and biodiversity. City-dwellers with proximity and greater exposure to natural environments (e.g. parks, gardens, woodlands, rivers and beaches) experience improved mental, physical and sociocultural health (Twohig-Bennett and Jones 2018, Lai *et al* 2019). Proposed mechanisms that explain these benefits include opportunities for physical activity and social contact, better psychological engagement (Lachowycz and Jones 2013) and improved microbial exposure (Flies *et al* 2017, 2018). Parks, streetscapes, gardens and informal green spaces maintain people's connection to natural environments, with flow-on effects for wellbeing and their support of biodiversity conservation (Miller and Hobbs 2002, Soga and Gaston 2016, Ives *et al* 2017). In a rapidly urbanising world, urban nature also plays a critical role in maintaining biodiversity. Urban vegetation enables the persistence of many plant and animal species (Lepczyk *et al* 2017, Threlfall and Kendal 2018). Threatened species live in cities, and depend on cities for their survival (Schwartz *et al* 2002, Ives *et al* 2016, Soanes and Lentini 2019). Urban nature also provides important ecosystem services such as cooling, storm water management, food production and recreation (Bolund and Hunhammar 1999, Dobbs *et al* 2014, Elmqvist *et al* 2015).

However, cities are highly diverse in size, function, character, land use, climate, infrastructure (Robinson 2006, Byrne and Houston 2020) and in the provision of, and demand for, urban nature (Boulton *et al* 2018). A city size bias in the literature has been demonstrated in urban climate solutions (Lamb *et al* 2019), and the literature suggests that studies of large cities in developed areas such as New York, Melbourne, Hong Kong, Berlin and London are likely to be overrepresented (Luederitz *et al* 2015, Boulton *et al* 2018, Filazzola *et al* 2019, Zhang *et al* 2020). Yet almost half the world's urban population live in smaller cities of less than 300 000 people (United Nations 2018), and urbanisation is now predominantly occurring in the developing world (Güneralp and Seto 2013). This suggests both a city size and geographic bias that could weaken the utility of the existing evidence base for most of the world's cities and urban dwellers. One of the drivers of bias may be a correlation between the location of researcher's institutions, and the location of cities they study—a phenomena that has been observed for Chinese scholars in urban ecosystem services research (Luederitz *et al* 2015).

Urban Scaling research shows that city size (based on total population) is a critical factor mediating many entangled economic, social and environmental facets of urban socio-ecological systems (Bettencourt and West 2010). City size impacts green space coverage, per capita access to green space and vegetation structure—all drivers of the ecological and human health benefits urban nature provides (Fuller and Gaston 2009, Zhao *et al* 2013, Dobbs *et al* 2017, Akuraju *et al* 2020). City-size affects the health outcomes associated with urban nature. Larger cities are associated with higher levels of physical activity and lower rates of obesity (Bettencourt *et al* 2007, Rocha *et al* 2015). City size also likely affects the benefits of urban nature for biodiversity. Applying island biogeography theory to cities suggests biodiversity is likely to be affected by city size via differing rates of species immigration and extinction (Davis and Glick 1978, Marzluff 2005), and the availability and connectivity of habitat. City size is also associated with the provision of some urban ecosystem services. City size is negatively related to total ecosystem service value (Wu *et al* 2013) and the recreation potential of vegetation cover (Dobbs *et al* 2014) (but not the potential for provisioning ecosystem services: Larondelle *et al* 2014). In combination, these findings strongly suggest that city size will influence the effects of urban nature through multiple direct and indirect pathways.

Clearly not all cities in the world have been or are ever likely to be studied, but biases in the evidence base could significantly undermine the utility of scientific knowledge informing urban nature policy for small cities or cities in the developing world (e.g. Bell and Jayne 2009). In other fields, there is concern that 'theoretical generalizations of empirical knowledge derived from global cities and metropolises' have been inappropriately applied to diverse small cities and towns (van Heur 2010, p 189). There are important economic, social, environmental and cultural differences in cities around the world that likely affect both the supply and demand for urban nature and the benefits it provides. There are radical differences in settlement patterns and vastly different health and biodiversity challenges in different places. Knowledge generated on urban nature in large cities will not necessarily apply equally to all cities, and applying this knowledge may be counterproductive in some settlements.

Here we aim to quantify evidence of city-size and geographic biases in the published scientific literature on the effects of urban nature on people and biodiversity by asking:

(a) Are the effects of urban nature more likely to be studied in large cities than in small cities (***city-size bias***)?
(b) Are researchers studying the cities they work in (***academic 'home' bias***)?
(c) Is there a geographic bias in studies of the effects of urban nature studies (***geographic bias***)?

Answering these questions will progress the urban nature research agenda towards better understanding of how nature associated with human settlements benefits human and non-human inhabitants across the spectrum of human settlements globally.

Table 1. Search terms used for our three categories of benefits from urban nature.

Search title	Search terms	Records returned
Urban biodiversity	TITLE-ABS-KEY ((urban OR city OR town OR metropolitan OR settlement) AND ('urban ecology' OR biodiversity))	10 094
Health benefits of urban nature	TITLE-ABS-KEY ((urban OR city OR town OR metropolitan OR settlement) AND (greenspace OR ('green space') OR garden OR ('open space') OR park) AND (health OR wellbeing))	3929
Urban ecosystem services	TITLE-ABS-KEY ((urban OR city OR town OR metropolitan OR settlement) AND ('ecosystem services')	3992

Table 2. Settlement size allocation to quartiles based on population and corresponding terminology according to key global organisations.

Quartile	Number of settlements	Population size	Total population	World bank	UN Habitat	UN World Population Prospects
Q1	42 281	5000–66 038	741 567 855	Town	Urban Cluster	Category 6
Q2	5576	66 039–335 414	741 577 575	City	Urban Centre	Category 6
Q3	1083	335 415–1759 999	741 316 978	City	Urban Centre	Category 4–5
Q4	165	>1 760 000	741 901 879	City	Urban Centre	Category 1–3

2. Methods

2.1. Literature on the effects of urban nature

To validate and determine the extent of potential city-size bias in the literature on the effects of natural urban environments, we systematically reviewed three bodies of academic literature:

(a) Urban ecology studies exploring the effects of natural urban environments on biodiversity
(b) Health studies exploring the effects of natural urban environments on people's health and wellbeing
(c) Ecosystem services studies exploring the services and disservices provided by natural urban environments

We accessed the Scopus bibliometric database API in October 2019 using the *rscopus* package in R v3.6 (R. Development Core Team 2010). Separate searches were conducted on urban ecosystem services, urban biodiversity and the health benefits of urban nature (table 1). These results of these searchers were filtered to exclude records with no abstract ($n = 262$) or that were not a journal articles ($n = 1703$), and duplicate records returned by multiple searches ($n = 1265$). Only English language articles were retrieved. The final list of articles included 14 786 articles, with 8921 from the biodiversity search, 3495 from the health search, and 3602 from the ecosystem services search.

2.2. City size and geographic data

A global database of 49 115 settlements with a population greater than 5000 residents was obtained from GeoNames (www.geonames.org/). There is no universally agreed definition of a 'city', nor a minimum population size required for a settlement to be considered 'urban'. We acknowledge that country- and region-specific thresholds can vary substantially, and a key challenge is to identify the boundaries of a city—to define what is urban and what is not—a decision that is usually made ad-hoc or based on administrative boundaries. In the absence of universal standards on these issues, we used a population size of 5000 as a minimum threshold in this study, consistent with thresholds used by global organisations such as the World Bank (Dijkstra *et al* 2020) and UN Habitat (Mwaniki 2018). The continent of occurrence of each city was determined by linking the country in the GeoNames database to continent using the Natural Earth country administrative dataset (Natural Earth 2019).

City size analysis often use a hierarchy of settlement sizes to demarcate different settlement types, although there is no consensus about where size boundaries begin and end (United Nations 2018, Lamb *et al* 2019). In this study, quartiles of urban settlements based on population size were determined so that each category included approximately the same number of people (table 2). The quartile of smallest settlements roughly corresponds to the world bank classification of town (Dijkstra *et al* 2020) and the UN Habitat classification of 'urban cluster' (Mwaniki 2018), both 5000–50 000 people. The second quartile roughly corresponds to the world bank classification of city (Dijkstra *et al* 2020) and the UN Habitat classification of 'urban centre' (Mwaniki 2018). In combination, the bottom two categories fall into the lowest category of city size as classified by the UN in their World Urbanization prospect reports, the Q3 cities map to UN city size categories 4–5 and the Q1 cities map to UN city size categories 1–3 (United Nations 2018).

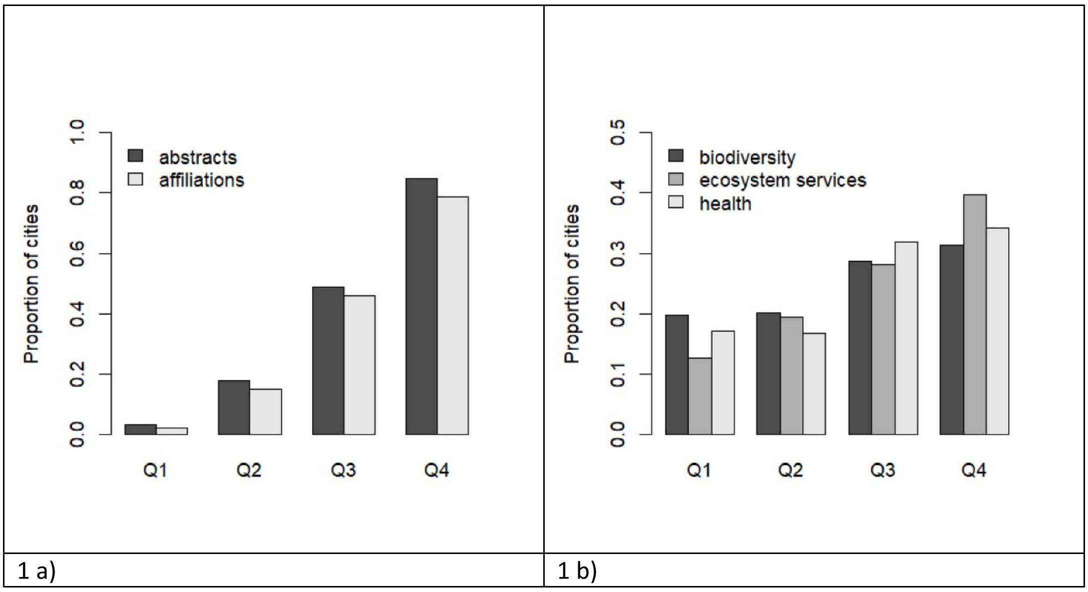

Figure 1. The proportion of cities mentioned in (a) all abstracts and affiliations and (b) abstracts returned by searches on urban biodiversity, urban ecosystem services and health benefits of nature, in each settlement size bin.

2.3. Data analysis

Text matching of city names with article meta-data was used to (1) identify article abstracts mentioning city names (study city), and (2) the city/cities of the institutions the authors were affiliated with (author city). Text was matched automatically using a custom R script to identify city names in abstracts and in author affiliations.

For each settlement size quartile, and for both study cities and author cities, the total number of articles mentioning the city, the proportion of cities in the quartile that were mentioned, and the average number of times each city was mentioned was calculated. The total number of publications and number of publications per 20 million inhabitants was determined for each continent.

2.4. Data cleaning and validation

City names that are also common words were excluded from the text matching (see supplementary material stacks.iop.org/ERL/15/124035/mmedia appendix 1). City names that were commonly confused with other names (states, regions, rivers, people) were refined using exclusion or inclusion criteria (see supplementary material appendix 2). The 327 non-unique city names, referring to 1190 unique cities, that were found regularly in abstracts (>3 mentions) were qualified using exclusion or inclusion criteria (see supplementary material appendix 3). Abstracts were cleaned to remove copyright notices that included city names (see supplementary material appendix 4).

To check the validity of the automated city name matching, 100 articles were randomly selected, and the abstracts were manually checked for false positives (city identified but no city name in the abstract) and false negatives (city in abstract not identified via automated text matching). This found 82% of abstracts were correctly coded, which was considered acceptable for the purposes of this study. There were 74 cities identified in the abstracts, 11 of which were false positives and 132 city names in the abstracts were not identified by the analysis. False positives were mainly caused by confusion with author names, province/state names and names of rivers and lakes. False negatives were largely caused by variation in spelling or the settlement having a population of less than 5000 people, and therefore not included in the master list of cities used in this study.

3. Results

A total of 7529 article abstracts were identified as containing at least one city name (51% of all articles), and 1778 articles mentioned more than one city name (with one abstract mentioning 25 cities). Cities were identified from author affiliations in 92% of articles.

3.1. City-size bias

An analysis of abstracts and affiliations shows that large cities are much better represented in the literature than smaller settlements (figure 1(a)). A minority of small cities have been studied (3% of the smallest quartile of settlements and 18% of Q2 cities), compared with a majority of large cities (85% of Q1 cities and 49% of Q3 cities). As these are quartiles based on population, this means that the smaller settlements where half the world's population live have been rarely studied. A similar pattern was observed in author affiliations; most large cities are mentioned in affiliations but only a tiny minority of small cities are mentioned. These biases are most pronounced

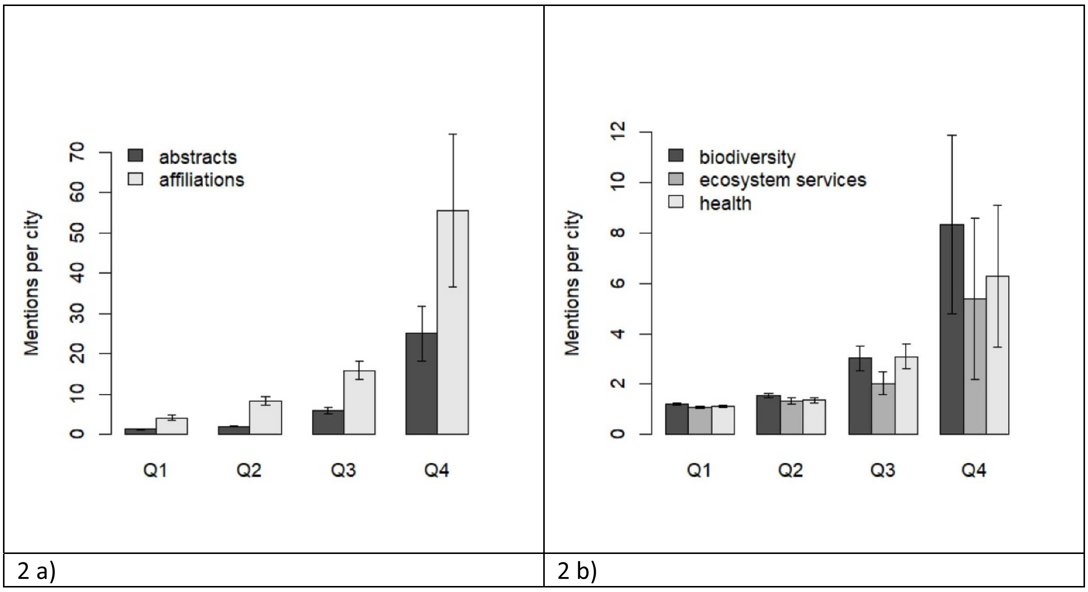

Figure 2. The average number of times each city is mentioned in (a) abstracts and affiliations and (b) abstracts returned by searches on urban biodiversity, urban ecosystem services and health benefits of nature, in each settlement size bin (95% confidence intervals are shown).

in studies of urban ecosystem services (figure 1(b)), although the same patterns were observed in studies of urban biodiversity and the health impacts of urban nature.

As well as large cities being more likely to be studied, large cities were also likely to have been more studied more often (figure 2(a)). Cities in the largest quartile were the subject of 25 studies on average, while smallest two quartiles of cities were studied only once or twice. Authors were also more likely to be affiliated with institutions in large cities (figure 2(b)). Q4 cities had an average of over 50 mentions in affiliations per city while small cities had fewer than 5. There was a great deal of variation in patterns of repetition across different search categories, making trends difficult to discern.

3.2. Academic 'home' city bias

Researchers are often writing about the cities in which they are working, with 45% of cities mentioned in abstracts also listed in the affiliation of one of the authors of the article. There was a strong correlation (Pearson $r = 0.84$) between the overall number of authors with an affiliation from a city, and the number of article abstracts mentioning that city.

3.3. Geographic bias

There was a clear geographic bias in the dataset (figure 3). Most studies were from Asia (in the developed cities of Beijing = 296, Shanghai = 104, Singapore = 83, Hong Kong = 81), Europe (Berlin = 106, London = 103, Barcelona = 77, Rome = 74) and North America (New York = 238, Chicago = 95,

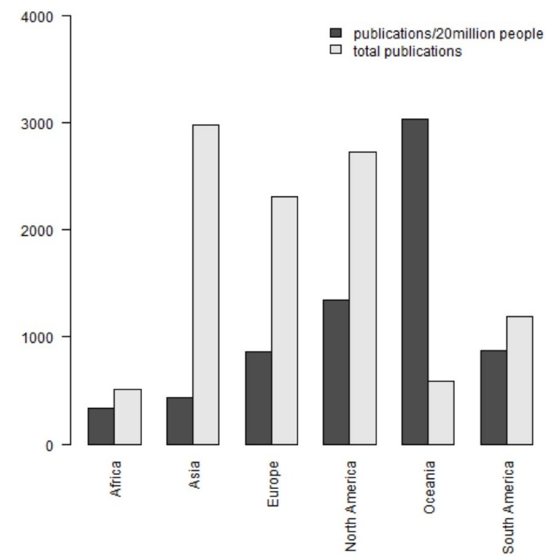

Figure 3. The total number of mentions in abstracts of cities on different continents, and by population (per 20 million human inhabitants).

Phoenix = 77, Baltimore = 73). The relatively few studies from Africa (Cape Town = 67) and South America (São Paulo = 118, Rio de Janeiro = 65) also tended to be from more developed or larger cities. On a per capita-basis, cities in Oceania (Australia and New Zealand) had a relatively low urban population but were the subject of a disproportionately high number of studies (Melbourne = 119, Sydney = 103). Conversely, cities in Asia and Africa that are home to much of the world's expanding urban populations were poorly represented.

4. Discussion

4.1. Key findings

There are biases in the published research on the effects of urban nature on people and biodiversity. First, bias towards the study of larger cities, which are studied many (~25) times over, while small to mid-sized cities are rarely studied at all. The most studied cities (Beijing, New York, Melbourne, Berlin, London and Shanghai) all have populations over 3 million people—consistent with in topic-specific reviews (Luederitz *et al* 2015, Filazzola *et al* 2019) and the quantified bias observed in climate solutions research (Lamb *et al* 2019). The methods used in this study have not captured studies where the city name is not included in the abstract, a likely scenario with some multi-city reviews such as meta-analysis or other big data studies. However, our findings likely capture a majority of primary research on the benefits of urban nature for people and biodiversity, as city names were found in more than half the abstracts analysed.

Currently, 41% of the world's urban population live in cities of less than 300 000 people (United Nations 2018). Current research on the effects of urban nature does not adequately capture the lived experience of the almost half the world's urban dwellers. Further reducing the diversity of cities studied is a bias of convenience; many studies are being conducted in cities where researchers work, consistent with findings at the country level by Luederitz *et al* (2015). Cities are complex social-ecological systems and having more studies per city allows greater diversity and depth in research topics. In small cities, fewer studies per city means less knowledge of different taxonomic groups and trophic levels, different classes of disease and diverse health and wellbeing pathways, and diverse ecosystem services and disservices. Larger research institutions in larger cities are more likely to have a greater number of researchers with more diverse research expertise, reinforcing the bias towards the increased extent and scope of research in large cities.

Geographically, rapid urbanisation is occurring across Asia, Africa and South America, but this review shows that there is comparatively little research on how urban nature can benefit developing cities in these locales (particularly outside a few large cities in Asia: Luederitz *et al* 2015, Lamb *et al* 2019, and as this review shows, in South America) This study only included English-language articles, and it is likely that articles in other languages would better represent South America, Africa and Asia. Yet the studies published in English and analysed here make an important contribution to global knowledge of the benefits of urban nature.

4.2. Does city size matter?

These biases will be important only if city size or geography influence the benefits derived from urban nature. There are several ways that city size could influence the mechanisms thought to underpin the benefits of urban nature. Firstly, smaller cities may facilitate easier access to *extra-urban* nature for humans (e.g. for recreation and physical activity) and non-humans (e.g. for foraging and habitat) which in turn affects the usage and importance of *intra-urban* nature. Island Biogeography theory provides a useful framework for thinking about connection of cities with extra-urban landscapes (Davis and Glick 1978), suggesting that movement of species (and humans) between urban and extra-urban areas will decrease in larger cities. This idea could be extended to the movement of other phenomena such as wildfire and both beneficial and nuisance animals (e.g. locusts, pademelons, deer).

Secondly, the composition and structure of urban nature, and therefore its functions and benefits, is likely to change with city size (Hahs and Mcdonnell 2006). Gradient studies have shown that urban nature changes along gradients of human population density, proportion of sealed surfaces, and distance from the urban edge (Hahs and Mcdonnell 2006). This gradient has been shown to have implications for biodiversity and health. For example, emerging evidence suggests that environmental microbiomes are shaping human health and wellbeing, and the microbiomes of urban green spaces almost certainly differ with city size (Laforest-Lapointe *et al* 2017, Flies *et al* 2017, 2019, 2020, Murray *et al* 2020). Many studies show the effects of levels of urbanisation on vertebrate biodiversity (e.g. Mckinney 2008).

Lastly, and perhaps most importantly, the effects of urban nature are highly context dependent, mediated by a diversity of geographical, ecological and socio-cultural factors (Luederitz *et al* 2015). Settlement patterns in these areas are radically different to the developed world. More than a billion urban residents live in informal settlements (slums) in the developing world, where urban densities are higher, sanitation and infrastructure are often substandard or missing. 'Nature' occurs more frequently in informal green spaces and where human-environment interactions are different (Boulton *et al* 2018). Urban ecosystem disservices are also likely to be different in developing countries, and the negative effects of urbanisation on people's health and wellbeing and on biodiversity conservation have been little studied outside global cities (Von Döhren and Haase 2015, Lai *et al* 2019). Evidence that is generated in a large global city may be irrelevant, or even counterproductive if applied in a different social-ecological context. There is a risk that evidence generated in the narrow context of large global cities may lead to normative beliefs about the role of all nature in all cities, without appropriate consideration of local context. For example, zoonotic diseases in tropical cities may be spread through some kinds of urban greening interventions promoted in Western cities. Increasing urban forest cover is often unquestioned as a policy goal, yet in some places, like those subject to wildfire, this could have harmful consequences (Moskwa *et al* 2018).

While some research has observed scaling effects in urban nature e.g. that larger cities have proportionally less green space (Fuller and Gaston 2009, Akuraju *et al* 2020), these scaling effects are not laws, and different effects may be observed on different collections of cities (Cebrat and Sobczyński 2016, Chang *et al* 2018). In fact, while large cities tend to follow urban scaling models closely, small cities are diverse and can display a great deal of heteroscedasticity in urban indicator data (Sarkar 2019). A critique of scaling analyses highlights that the urban functions of small cities are the result of complex intersections of many factors, and must be understood 'in place' (Waitt and Gibson 2009).

4.3. Towards an urban nature research agenda for all urban dwellers

'*Without incorporating the study of small cities more fully into urban research, we shall fail in the task of understanding cities in their diversity, their connectedness and their distinctiveness.*' (Bell and Jayne 2009, p 696). We extend this to call to the study of urban nature and its effects on human and non-human life.

4.3.1. Addressing city size and geographic biases

One pathway to this goal is for researchers to carefully consider the design of their research, and to study cities that can best answer their research questions rather than those conveniently accessible (i.e. where they live, work or study). There are many good reasons for studying local cities including knowledge of cultural, socio-economic and historical context and potential pathways to impact and engagement. However, research design may be improved and better answer research questions by explicitly considering different cities or extending a study to compare multiple cities. Recognising that researchers will continue to 'oversample' the cities they work in, collaborations between researchers that span institutions in different cities, between institutions in developing and developed countries, and leverage networks of cities (e.g. ICLEI) may facilitate the study of a greater diversity of cities.

4.3.2. Moving beyond urbanisation gradients

While gradient studies have contributed much to our understanding of nature in urban systems, studying mechanisms rather than level of urbanisation may further develop knowledge. Many gradient studies of urban biodiversity and ecosystem services use population density as a measure of urbanisation (e.g. Tratalos *et al* 2007, Luck *et al* 2009, Peng *et al* 2017, Moreira *et al* 2019, Łopucki *et al* 2020). This focus on population density could confound understanding of alternative mechanisms, such urban scaling effects from total population, environmental context or local habitat characteristics. A greater use of comparative studies across different cities could improve understanding of these factors (Mcdonnell and Hahs 2009) and also reveal how interactions between biodiversity and human health vary between cities. The study of urban teleconnections could lead to better understand the processes underpinning movement of species, people, technology and culture between different spatially discreet urban, peri-urban and rural areas (Seto *et al* 2012).

4.3.3. Avoiding gross urban-rural dualisms

We cannot assume that the benefits of nature will be the same in smaller urban contexts as in large cities. Much of literature surrounding the effects of urban nature is grounded in gross rural-urban and natural-built environment dualisms which fail to reflect the diversity of urban environments and the permeability of contemporary urban/peri-urban/rural intersections (Tornaghi and Dehaene 2020). In Australia, the disease burden rate in the most rural areas is 1.4 times the rate in major cities (Australian Institute of Health and Welfare 2019) despite extensive access to natural environments. Health benefits derived from nature may be different in smaller cities than in large cities, and the health inequities that occur in rural areas may extend to into smaller urban settlements. Reducing the big-city bias in urban health, biodiversity and ecosystem service literature that we have revealed here is needed to better understand nuances, complexity and normative thinking in the benefits of urban nature.

4.3.4. Contextualising existing research

Care must be taken when generalising findings from large cities to small cities, or across cultural or development contexts. Scientific findings and evidence from Stockholm, London or New York may not be easily generalisable to Hobart, Puntas Arenas or Cà Mau. For example, education level rather than income has been shown to drive patterns of vegetation diversity and cover in small cities in south-eastern Australia (Luck *et al* 2009, Kendal *et al* 2012). In rapidly growing cities in Africa, Asia and South America, urban nature may be more important as a source of firewood, fresh food, medicines and cultural practices (e.g. Kaoma and Shackleton 2014) than in Western cities. Different values towards nature, such as wood gathering and subsistence activities in African settlements or the sacredness of some trees in

Indian cities (Jaganmohan *et al* 2018), will likely produce different urban ecologies, and applying Western norms and ideas about nature to such places, without studying them, will produce ethnocentric biases. Care should be taken when generalizing findings to a particular city to ensure comparisons are made with an adequate and representative sample of cities. In quantitative generalisations, weights could be applied to help correct biases in the evidence base. City managers need information on urban biodiversity management that can be taken and applied to their own city social, cultural and environmental context.

5. Conclusion

There is strong evidence base of the many positive effects of urban nature on biodiversity, ecosystem services and human health. However, several important biases exist in the literature that raise questions about the utility of this literature as an evidence base for urban policy in the diverse cities that exist in the world. There is an over-representation of studies in the large cities where research institutions are located, and a lack of studies in small cities and in developing areas. Urban scaling effects are likely, the results of studies in big cities should not be blindly translated to small and regional city contexts. In the coming decades, small to mid-size cities will remain important sites of human existence and human-nature interactions. Diversifying the sites of urban nature studies and a greater emphasis on multi-city research partnerships should lead to a more robust evidence-base, and more effective application of urban nature research and in cities around the world.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).

ORCID iDs

Monika Egerer https://orcid.org/0000-0002-3304-0725
Gabriella Allegretto https://orcid.org/0000-0002-5384-3699

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