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Outstanding challenges for urban conservation research and action

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ABSTRACT

Researchers, advocates and policymakers have proposed urban conservation as an emerging, integrative discipline that can contribute to sustainable cities by delivering co-benefits to human and non-human components of biodiversity. Given the recent growth in biodiversity-friendly designs and management schemes, there is an urgent need for a synthesis of this fragmented research base to inform planners and decision-makers. We conducted a systematic multidisciplinary literature review (787 papers) and found that the importance of urban areas for general conservation is not convincingly supported by empirical research. Only few studies demonstrated that cities can directly contribute to conservation efforts, by hosting viable populations of rare or endangered species, or by providing green corridors for the passage of natural populations. From a social perspective, while several studies demonstrated that green infrastructure could provide services for people (notably cultural services), only few studies explored the role of species diversity per se. Our review also shows strong geographical, location and taxonomic biases in urban biodiversity conservation research that make generalisations difficult. It is a disturbing paradox that while research in urban biodiversity conservation is rising exponentially, the main motivations for conserving urban biodiversity remain largely untested and unproven. We thus propose a framework for promoting integrative urban conservation research to bridge those gaps. Together, these findings warn against expanding cities under green planning and call for enhancing biodiversity experience by improving the quality of existing green spaces throughout the entire urban matrix. We provide a set of recommendations for practitioners and decision-makers to continue action.

1. Introduction

Urban landscapes are rapidly expanding, replacing or degrading more natural environments and reducing the experience of nature for over half of the world's population (Miller, 2005). Today, there is increasing concern about how to design sustainable cities that reduce those detrimental impacts and provide multiple benefits to people and the environment. Urban biodiversity is increasingly viewed as an opportunity to combine multiple benefits, both locally through ecosystem services and globally for biodiversity conservation (Miller and Hobbs, 2002; TEEB, 2011). An evaluation of the potential of these co-benefits is currently hampered by the fragmented scientific knowledge on the benefits of urban biodiversity to both global conservation and city dwellers. Understanding these issues would help decision-makers and planners determine how to allocate and manage the limited space and resources devoted to nature in the city.

Nature is an integral part of cities, historically shaped by city planners to enhance human well-being (Dubost and Lizet, 2003). Today, there is also a growing understanding that urban green spaces can harbour a rich diversity of species, which sometimes even exceeds that found in nearby less urban environments (reviewed by McDonnell and Hahs (2008); McKinney, 2008; Faeth et al., 2011). Over the past decades, biodiversity-friendly designs and management schemes have burgeoned, with some success at increasing local biodiversity (Sadler et al., 2010; Shwartz et al., 2013). But the effectiveness of these measures for global conservation and human well-being is still insufficiently understood. From an ecological perspective, management efforts to conserve urban biodiversity may not always be good for conservation per se. For instance, when these efforts are used to justify the spread of cities over more natural areas (Sushinsky et al., 2013), or when green

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infrastructure only hosts common urban adaptors and alien species (McKinney, 2010). From a social perspective, while the importance of urban green spaces and nature for individual well-being of city inhabitants is consensually recognized (reviewed by Tzoulas et al., 2007; Keniger et al., 2013), it is not yet clear to what extent people experience and benefit from the complexity of urban nature (i.e., biodiversity; Fuller and Irvine, 2010). Moreover, some management decisions concerning urban nature may sometimes trade-off against social benefits. For instance, while lawns are one of the city dwellers' favourite types of urban green space, it has been shown that well-maintained lawns offer poor conditions for many species (Gaston et al., 2005; Shwartz et al., 2008). It thus remains unclear which place should be awarded to biodiversity conservation in cities, given the many other competing demands in urban management (McDonnell and Hahs, 2013).

There is thus a need for systematic synthesis to aid future decision-making and research. Urban conservation is emerging as an interdisciplinary field that explores people, biodiversity and their interactions (Pickett et al., 2008). The increasing interest for this discipline over the past 20 years is reflected by the increase in the number of papers published yearly (Fig. 1). However, any evaluation of the importance of conserving urban biodiversity in cities, as in other disciplines, remains difficult for three main reasons: (1) published studies are disparate, across disciplines, geographical regions and locations within the urban environment, which creates a segmented, contextually-limited understanding of the issues (Alberti and Marzluff, 2004; Goddard et al., 2010; Cook et al., 2012); (2) studies are of different types, i.e. they focus on different taxonomic groups, target a range of ecological questions (e.g. behaviour, urban–rural gradients, island biogeography) and use a mix of qualitative and quantitative methods (e.g. field observations, people's interviews, satellite information), which makes it difficult to pool data across studies (Cook et al., 2012). Yet, all these studies may contain relevant information to help understand the value of urban biodiversity; (3) knowledge is not expressed in a consistent terminology (McIntyre, 2000; Miller et al., 2008). As with any emerging interdisciplinary fields, a challenge is to create a common language, since currently studies often use different terms to refer to similar and overlapping concepts. For instance, ecologists typically refer to species richness or abundance, whilst social scientists talk about urban nature and green cover and economists about ecosystem services to express biodiversity-related issues. A mapping of the existing knowledge will help identify research gaps and needs, as well as prioritize conservation actions.

An important large-scale attempt to synthesize this research base was work by Dearborn and Kark (2010), who identified five testable motivations for conserving urban biodiversity. A first set of motivations is directly linked to global biodiversity conservation. It includes "target species conservation" (1), i.e. protecting important populations of unique, rare or endangered species (hereafter referred to as target species), and "corridors and stepping stones" (2), i.e. creating stepping stones or corridors allowing the passage of natural populations through the built environment (e.g., Cincotta et al., 2000; Jordan et al., 2003; Hodgkison et al., 2007). The second set of motivations is more social, concentrating on how conserving urban biodiversity could mutually benefit people and nature. These motivations include "ecosystem services" (3), i.e.

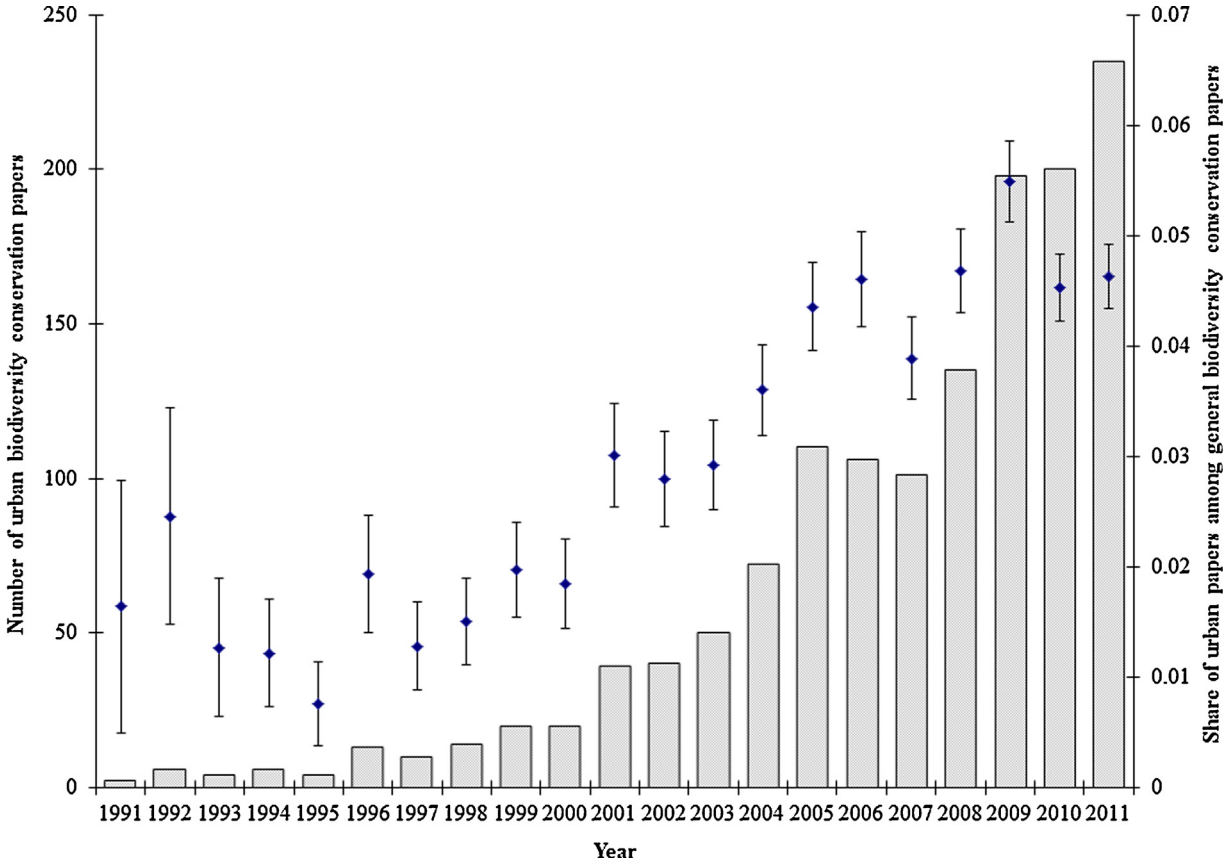

Fig. 1. The number of urban biodiversity conservation papers published between 1991 and 2011 (bars) and the proportion of urban biodiversity studies in the general biodiversity conservation literature (dots: proportion ± SE) are presented. The number of urban papers was calculated using a search for the keywords urban and biodiversity and conservation in the ISI Web of knowledge database. The proportion of biodiversity studies was calculated by dividing the latter by the number of general biodiversity conservation papers (conducting a similar search excluding the word 'urban'), showing that the rate of increase in the number of urban biodiversity papers exceeds that of the general biodiversity conservation literature.

healthy urban ecosystems can provide a number of services to people (Bolund and Hunhammar, 1999; TEEB, 2011); "cultural services" (4), which receive a lot of emphasis in cities because they are strongly connected to the quality of life of city dwellers (e.g., Savard et al., 2000; Miller and Hobbs, 2002); and "conservation education" (5), since urban biodiversity offers an important potential for connecting people with nature and raising public awareness for conservation issues (e.g., Miller, 2005; Dunn et al., 2006; Faeth et al., 2011).

However, Dearborn and Kark (2010) did not give a systematic and quantitative account of what is known about these motivations, i.e. how they are studied and whether they are scientifically supported. In this paper, we therefore provide a systematic and multi-disciplinary review of what is known about the value of urban biodiversity for conservation and city dwellers, in different parts of the world and of the urban environment. We thus reviewed the empirical evidence investigating the five central motivations in urban biodiversity conservation put forward by Dearborn and Kark (2010). We provide a quantitative overview of these studies and examine whether they are supported by empirical evidence using conceptual meta-analysis methods (Hoffman et al., 2011). We also examine where studies are been carried out (both on a global scale and within the urban environment) and which taxa are frequently studied. Using this scientific knowledge-base we identify research gaps and suggest a framework for promoting integrative urban conservation research. We then provide scientifically-grounded recommendations for conservation action, so that on-the-ground efforts may provide co-benefits to people and biodiversity.

2. Methods

2.1. Selection of papers for inclusion in the systematic review

We conducted a comprehensive scientific literature review in five disciplines (Ecology, Geography, Economics, Education and Sociology), searching papers published between January 1980 and February 2011 (this represents much of the research; Fig. 1). We searched the common databases used in each of the five disciplines (Table S1), ensuring that they provided a good coverage of narrower relevant disciplines such as Landscape Architecture or Urban Planning/Ecosystems. To reduce reviewer bias, we conducted a systematic literature review following a strict protocol. Altogether, we carried out 22 literature searches (Table S1). First, we conducted five general searches (i.e., one in each database) for urban biodiversity conservation studies (Table S1). Then, we conducted an additional 17 searches (Table S1) with specific keywords related to a set of criteria that an article had to meet to be considered a source of empirical evidence supporting one of the motivations. For each search, we test-trialled several keywords and selected the ones that maximized the number of relevant results in all of the five databases. Keywords were then searched in all of the available fields (e.g., abstract, title, keywords, etc.). Non-English language searches were not conducted in this review.

See Table S1 as supplementary file. Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.06.002.

We performed a three-fold filter process before accepting a study into the final review. First, we scanned titles and filtered out all books, non-empirical studies (e.g., opinions and reviews) and obviously irrelevant papers (e.g., when urbanization was mentioned as a threat for biodiversity, but no study of the urban environment was performed). In a second step, we carefully read the abstracts of the remaining studies, excluding papers that did not focus on the urban environment or that did not study any nature-related topics. The World Resources Institute (2000) defines the urban environment as 'a biological community where humans represent the dominant or keystone species and where the built environment is the dominant element controlling the physical structure of the ecosystem. We therefore included papers studying all varieties of urban settlements, from large metropolises to small residential towns in the exurban and suburban matrix, as well as papers that studied urban greenness or land-use and not necessarily biodiversity. In the third and final filter stage, all studies that passed the first two criteria were read in full and either rejected or accepted into the final review according to the above-mentioned filter criteria. Altogether, the 22 searches yielded 3872 references (after excluding duplicates), and 787 papers remained after the three filter stages (see Table S2 for a full list of papers and results). These papers were published in 272 different journals covering various disciplines, notably urban studies and conservation biology (e.g., Landscape and Urban Planning, Urban Ecosystems, Biological Conservation). Although we only used search terms in English, 47 of the relevant studies were written in other languages. Out of which 31 studies in French, Spanish, German, Italian and Portuguese were included and 12 studies in Chinese, Japanese and Russian were excluded based on our linguistic capabilities.

See Table S2 as supplementary file. Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.06.002.

Our systematic review did not cover grey literature (i.e., informally published written material such as reports) because we were aiming to find empirical tests for the motivations; therefore, we focused on quantitative primary and peer-reviewed evidence. Nevertheless, considerable amounts of bottom-up initiatives exploring nature-based solutions in cities are documented in the grey literature. Although it is difficult to survey the grey literature in a systematic way, evidence shows that both the scientific and grey literature focus mostly on public urban green infrastructure and share the same set of motivations (Dearborn and Kark, 2010; TEEB, 2011; McDonnell and Hahs, 2013). However, to our knowledge, these studies rarely focus on quantitatively measuring whether attributes of urban ecosystems, such as species diversity, contribute to achieving conservation- or people-oriented motivations.

2.2. Evaluation of the search efficiency

We evaluated a posteriori our efficiency in detecting studies that provided evidence to support the motivations. This was done by recording in each out of the 787 reviewed papers each reference that was quoted in support of one of the motivations. We then checked whether this reference already appeared in our reference list. In this a posteriori search, we found 134 references quoted to support one of the motivations. Among those references, 38 did not correspond to our review criteria (i.e., books, reviews and papers published before 1980) and 67 (i.e., 70% of the remaining papers) already appeared in the 787 reviewed papers. Thus, our review missed 30% of the papers corresponding to our review criteria ($n = 29$). Most missing papers were quoted to support the cultural services motivation (66% of the papers that did not match the review criteria and 45% of the missing papers) and often focused on the well-covered relationship between well-being and urban green spaces or nature (reviewed by, Tzoulas et al., 2007; Keniger et al., 2013). Thus, these papers in fact did not explore the role of biodiversity per se. Therefore, it appears that we satisfactorily achieved our objective of providing an unbiased reflection of the research in urban conservation, with a small caveat for cultural services.

2.3. Mapping of urban biodiversity research by motivation

We classified all 787 papers between those that attempted to directly test one of the motivations (direct test) and those that had

the potential to provide evidence to support one of the motivations (indirect test; see Table 1) suggested by Dearborn and Kark (2010). Indeed, papers that did not directly test or even state a motivation related to urban conservation could still find results supporting one of the motivations. For example, Hall et al. (2002) aimed to examine how landscape parameters influenced urban scrub community and did not mention any specific motivation related to urban conservation. However, alongside their main results, they reported the presence of six endangered and threatened scrub species, which can be important for conservation.

We established five criteria (one for each motivation) to establish the number of papers that could have provided indirect results:

1. Target species conservation: we considered three groups of species as target species: (1) threatened and endangered species, based on the IUCN Red-List categories of CR, EN, VU (IUCN, 2008); (2) nationally rare species (established based on authors statements and confirmed in some cases by reviewing the quoted references); and (3) unique species (species that were reported to be found only in urban environments and not elsewhere). For this group we considered papers that either studied one or more populations of target species, or papers that sampled and reported information on communities of fauna or flora.
2. Corridors and stepping stones: for this group, we considered any paper that aimed to test connectivity or corridors and stepping stones, or papers that calculated some index of connectivity between sites within the urban environments or between urban and more natural landscapes.
3. Ecosystem services: for this group, we considered papers that physically measured, monitored, estimated or validated any provisioning or regulating services in the urban environment.
4. Cultural services: for this group, we considered any paper that explored people's perception regarding green spaces, nature, plant and animal species, biodiversity, biodiversity-friendly management, etc., or studies that explored the relationship between well-being and urban green spaces/nature.
5. Conservation education: for this group, we considered any paper that either explored any interaction between people and species (positive or negative) or papers that reportedly described conservation education initiatives and their impacts.

2.4. Evaluation of the effectiveness of urban biodiversity conservation

We then looked at the outcome of each study to determine whether it provided direct or indirect support for a given motivation (Table 2), according to the pre-defined criteria set out in Table 1. Indirect support was established by quantifying the share of papers that provided empirical evidence for a motivation from the population of indirect test papers. The evaluation of indirect support allowed us to partly address the caveat of publication bias (Jennions and Møller, 2002), because studies that failed to find support for one of their initial hypotheses might have then published their results under a more modest goal. Unfortunately, the small number of studies directly aiming at testing the motivation and the broad variation in the type of investigation and range of outcome measures adopted in the indirect studies precluded the use of formal meta-analytical techniques for quantitative analysis.

2.5. Geographical location, urban location and taxonomic context

For each out of the 787 papers, we recorded the geographical location (i.e., the country in which the study was conducted). Based on the description provided by the authors, we further classified each paper into one of four urban location categories and an additional 11 subcategories (Table 3). We then used chi-square to compare the number of studies per country to the expected number, assuming a distribution that is proportionate to the country's urban land cover (taken from Angel et al., 2010). Similarly, we compared the number of studies focusing on greenspaces with the expected number of studies calculated based on the share of greenspaces in European cities (Fuller and Gaston, 2009). Although these hypothetical distributions are

Table 1
For each motivation, criteria are used to identify the group of studies that set out to test the motivation and to determine whether the outcome supported the motivation (columns 2 and 3). Similar criteria were defined for studies that did not set out to test one of the motivations but which could provide relevant evidence in support of or against a motivation (columns 4 and 5).

Motivation	Direct support of the motivation		Evidence supporting the motivation	
	Set of studies	Desired outcome	Set of studies	Desired outcome
Target species conservation	Studies testing whether the urban environment can protect viable populations of species with conservation value	Populations of species with conservation value are viable in cities, similar or better than in nearby greener environments	Studies reporting results on species communities, or exploring populations of species with conservation value	Urban environment hosts populations of species with conservation value
Corridors and stepping stones	Studies testing the role of urban green infrastructure as stepping-stones or corridors for natural populations	Green infrastructure allows the movement of species between natural populations	Studies exploring the influence of connectivity on populations or species diversity (within the urban environment, or between urban and natural environments)	Green infrastructure increases connectivity (within the urban environment, or between urban and natural environments)
Ecosystem services	Studies testing the role of biodiversity in provisioning/ regulating of ecosystem services in the urban environment	Positive relationship between physically measured provisioning or regulating of service and species diversity	Studies that have physically measured or monitored provisioning or regulating of ecosystem services	Greenness/plants or individual species provide provisioning or regulating of ecosystem services
Cultural services	Studies testing the role of biodiversity in providing cultural services in the urban environment	The well-being of city dwellers is positively related to biodiversity	Studies exploring people's perception of nature, greenness or of individual species	Nature, greenness or individual species valued by city dwellers or positively related to their well-being (but not biodiversity)
Conservation education	Studies testing the role of interactions with urban nature in promoting a connection to nature or conservation awareness	Interacting with urban species increases their connection to nature and conservation awareness	Studies exploring people's interaction with wildlife or exploring a conservation education activity	Encounters with urban biodiversity or participation in a conservation education activity connects people to nature or increases their conservation awareness

Table 2
Number of studies within the primary research that aim to test the main motivations for studying urban biodiversity or that can provide relevant evidence and support found for these motivations.

Motivation	Total number of papers providing supportive evidence	Share of papers that supported the motivation among the papers that aimed to test it	Share of papers providing supportive evidence for the motivation among the papers that did not aim to test it
Conservation-oriented[a]	105		
Target species conservation	80	3/3	77/478
Corridors and stepping stones	28	3/6	25/60
People-oriented[a]	66		
Ecosystem services	19	3/4	16/53
Cultural services	44	1/1	43/55
Conservation education	4	2/2	2/17
Not found	616		

[a] Because several papers provided support for more than one conservation motivation and people-oriented motivation, the sum of the sub-categories may exceed the total number of papers in the category.

unrealistic, they are useful in describing the relative study effort in each country (Martin et al., 2012) and whether interest in greenspaces was proportionate to the share of these areas in cities.

Studies were also classified into three main subject categories: (1) people: interdisciplinary or social studies that examined people's perceptions and actions with or without accounting for urban biodiversity or urban greenspaces; (2) urban green spaces or land use: studies that focused on land use or green indices in the cities; and (3) biodiversity: studies that focused only on biological diversity in urban areas, classified into eight sub-categories (Table 3) following Fazey et al. (2005). Chi-squared tests were used to explore the differences in the distribution of taxa studied in general conservation studies (Fazey et al., 2005) versus the distribution of taxa studied in urban conservation studies.

3. Results and discussion: the importance of conserving urban biodiversity

It is becoming an established paradigm that greening cities could have measurable benefits for regional biodiversity conservation and generate ecosystem services on which urban communities can rely (McDonnell and Hahs, 2013). But although such generalizations are increasingly accepted and promoted in conservation actions (e.g., TEEB, 2011), the scientific evidence has never been thoroughly assessed. Perhaps since the volume of research was not yet sufficient in this emerging field. Nevertheless, our results rather astonishingly show that the central hypotheses of urban biodiversity conservation are still rarely investigated. Evidence is thus still insufficient to determine the value of urban biodiversity for general conservation efforts and for people's quality of life. We found only 16 studies that directly tested one of the stated motivations (Table 2). In light of insufficient evidence, this systematic review highlights some gaps in scientific knowledge (Fig. 2), which can be translated into several priority research areas (Cook et al., 2013). In the following, we detail these research priorities and our proposals for management of urban biodiversity.

3.1. Research priorities

3.1.1. Research priorities regarding conservation-oriented motivations

The importance of urban areas for general conservation is not convincingly supported by scientific research. Eighty papers altogether showed that target species could occasionally be found in urban areas (Table 2; e.g., Schwartz et al., 2002). However, the presence of target species in the urban environment is not a sufficient indication of effective conservation and urban environments can sometimes be sinks or ecological traps for several taxa (reviewed by Battin, 2004). Only six studies reported that populations of target species in the urban environment were viable and performed similarly than in nearby greener environments (e.g., Lawson et al., 2008). An additional two studies showed that target species were both viable and performed better than in nearby greener environments (Cypher and Frost, 1999; Harveson et al., 2007). Future research should therefore go beyond exploring

Table 3
Distribution of research subjects, urban locations and geographical regions in the primary research on urban biodiversity conservation.

Research subjects		Urban locations		Regions[a]	
People	56	Green spaces[a]	486	Africa	19
People and biodiversity	16	Remnants	207	Asia	88
People and urban green spaces	18	Green spaces	113	Europe	263
Urban green/land-use	75	Parks	127	Latin-America	57
Biodiversity	622	Freshwater	56	North-America	259
Invertebrates	146	Seawater	14	Oceania	115
Plants	157	Wastelands	16		
Birds	142	Residential areas[a]	60		
Multiple	68	Private gardens	32		
Mammals	56	Streets and roads	24		
Herptiles	35	Private houses	16		
Fish	15	Downtown	5		
Fungi and Lichen	3	Residential building	5		
		Several locations[b]	109		
		Not defined[c]	132		

[a] The sum of papers within the category can exceed the total number of papers reported, since several papers were studied in more than location or were conducted in more than one country or even regions.
[b] Papers that studied several locations or used spatial analyses across the urban area.
[c] Papers that did not mention the exact location in the urban environment.

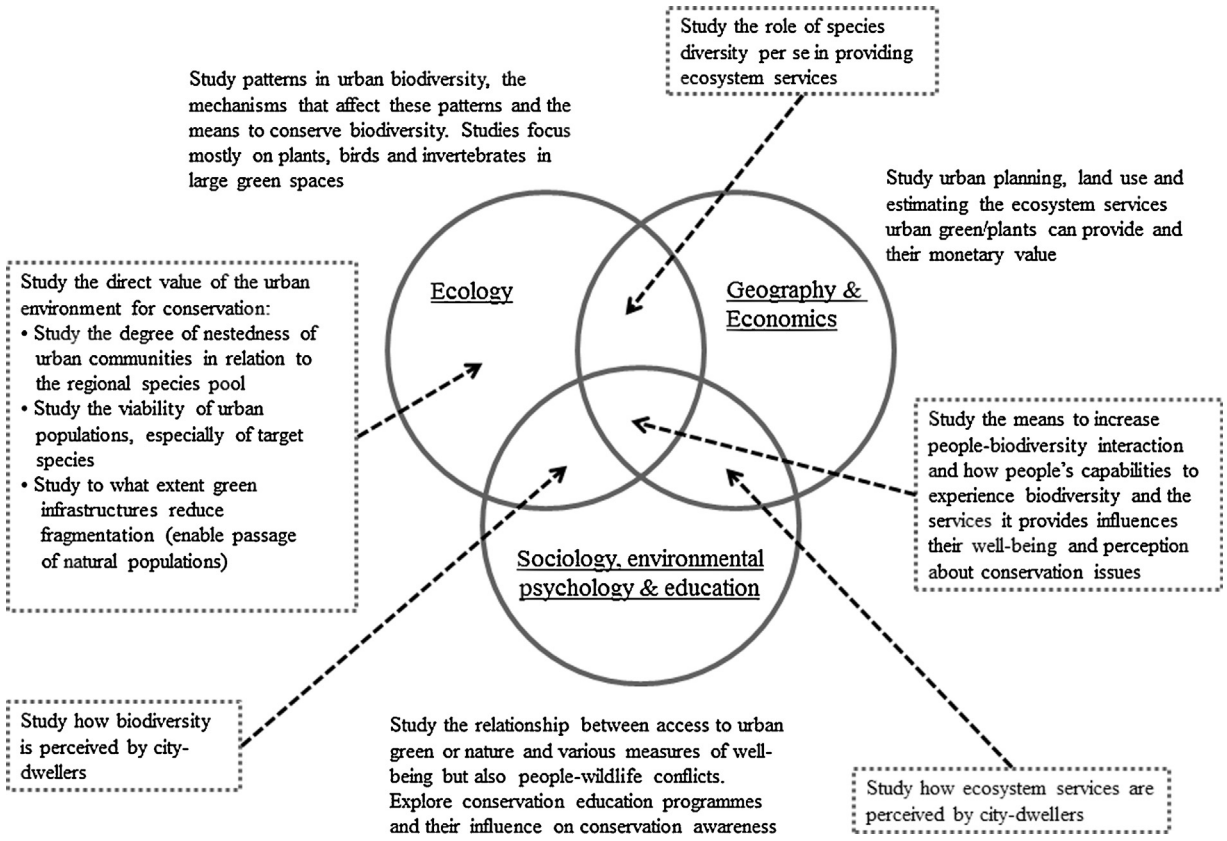

Fig. 2. The main sphere of research for the different disciplines of urban biodiversity conservation. The Venn diagram represents possible research interests, as reflected by our review. Each circle represents the main set of interests in each of the three main conservation research disciplines reviewed, and their overlap shows the potential areas of interaction among disciplines. The grey dashed boxes highlight research gaps in establishing the motivations for conserving urban biodiversity. This figure does not aim to cover all possible interactions in urban conservation research; rather, it provides a summary of the results as reflected by this literature review.

whether target species can occur in cities to assess whether they can establish viable populations (Fig. 2; Kowarik, 2011). Such research may also need to take into account that the urban environment can influence the behaviour of species and initiate a process of speciation from rural populations (Slabbekoorn and Ripmeester, 2008).

It would be incomplete to assess conservation-oriented motivation solely based on target species, because the urban environment may also help conserve common biodiversity (Gaston, 2010). Indeed, several studies in this review ($n = 47$) and in other studies (reviewed by McKinney, 2008) revealed that species diversity (mostly plants) could peak at an intermediate level along an urbanization gradient (e.g., suburbs). However, this does not provide robust empirical support for justifying the planning of 'green' sprawling cities. First, only few of those studies actually quantify the level and type of disturbance along the urbanization gradient (e.g., fragmentation and pollution). Second, current knowledge does not provide evidence that a sprawling type of urban development has lower ecological impacts than a compact form of urban development, which requires less land, but also offers less opportunity for biodiversity within the city (Sushinsky et al., 2013). We therefore would like to argue that exploring the conservation value of urban biodiversity necessitates a regional or landscape approach, that goes beyond simply quantifying the diversity of species. This would ideally involve investigating the nestedness of urban species in relation to the regional species pool (e.g., Fuller et al., 2009; Sattler et al., 2011) and spatial modelling to explore trade-offs between different types of urban developments (e.g., sparing vs. sharing; Sushinsky et al., 2013). Such an approach would help highlight those instances where greening cities could be beneficial, for instance when it can provide a habitat for native species that struggle nearby due to the pressure from agriculture.

The notion that green infrastructure can form a set of corridors or stepping stones that could reduce fragmentation was supported by 42% of the 66 studies that investigated this hypothesis (Table 2). Publication bias is less likely to be an issue for this hypothesis than for the others, because this hypothesis was often tested alongside other environmental hypotheses. The vast majority of these papers showed that green spaces with higher levels of connectivity were more species diverse (e.g., Bino et al., 2008) and predominantly looked at birds and mammals (25 studies). Thus, corridors or stepping stones facilitated movement to, within or from urban ecosystems. However, this finding does not prove that natural populations benefit from using this green infrastructure; only three papers that directly aimed to test the usage of corridors by natural populations demonstrated their usefulness (Table 2; e.g., Bender et al., 2004). Further research in population genetics and movement ecology would help to establish the characteristics of green infrastructure that effectively reduce fragmentation for different sets of species. Urban ecological research should thus advance beyond the observational study of species diversity to directly test the two conservation-oriented motivations. This calls for integrating a population-based approach (i.e., demography, behaviour, genetics) with movement and landscape ecology (Fig. 2).

3.1.2. Research priorities regarding people-oriented motivations

The role that species diversity per se plays in providing ecosystem services was tested directly in only four studies, three of which supported it empirically (e.g., Lundholm et al., 2010). Among the 53 studies that partially explored the ecosystem services

motivation, 16 (30%) showed that: (1) some insects can provide pollination services (e.g., Lomov et al., 2010); (2) the presence of green or plants could improve some urban ecosystem functions (Jim and Chen, 2008); and (3) provide resources for urban inhabitants (showed mostly in developing countries; e.g., Bernholt et al., 2009). It is possible that a higher diversity of species provides a higher diversity of services and improves service quality (Lundholm et al., 2010) or is required for urban ecosystems to function well. However, we are not aware of any study that empirically examined these central hypotheses in the urban environment. In particular, research looking at the trade-offs among the provision of different types of services in the urban environment is completely lacking. Therefore, further research at the interface between ecology, geography and economy (Fig. 2) is needed to answer these questions.

Although people are the main drivers of the dynamics of urban ecosystems, very little is known about the relationships between biodiversity and people in cities. With regard to cultural services, a single paper tested this hypothesis and demonstrated that plant diversity was correlated with people's well-being (Fuller et al., 2007). However, another 43 studies (78% of the papers that did not test this hypothesis directly) provided some partially supporting evidence (Table 2). Thirty-seven studies showed a positive correlation between urban green spaces or nature and people's well-being (Table 2), and an additional six papers demonstrated that people value biodiversity, animal or plant species. Therefore, cultural services are better supported overall than the other motivations. Nevertheless, the emerging literature that explores the psychological benefits that biodiversity can provide for city-dwellers reveals that this relationship is not as straightforward as is commonly argued. People's awareness of the surrounding biodiversity and their ability to benefit from it varies with their ecological expertise, the type of green space and the taxon considered (Fuller et al., 2007; Dallimer et al., 2012; Shwartz et al., 2014). Two difficulties further muddy the waters: greenness and biodiversity are often considered as interchangeable concepts, and truly interdisciplinary studies setting out to explore both people and biodiversity are scarce ($n = 16$, Table 3). Therefore, more interdisciplinary research is needed to shed light on the intricate links between people's perception of biodiversity and their capabilities to experience and benefit from this biodiversity in different contexts (Fig. 2). Such research would be instrumental for planning and managing green spaces.

We found only limited support for the urban conservation education motivation. Only four of the reviewed papers (Table 2) showed that interaction with urban wildlife or participating in conservation education programmes influenced people's attitudes towards conservation and pro-environment behaviour (e.g., Bjurlin and Cypher, 2005). The majority of studies that explored this hypothesis remains descriptive and does not validate the efficiency of conservation programmes.

Urbanization is modifying the relationship of people with nature (Miller, 2005), increasing the risk that city dwellers may gradually lose their capacity to experience nature's complexity (Dallimer et al., 2012; Shwartz et al., 2014). This effect could have far-reaching implications on the way people value nature and benefit from it. Therefore, the challenge at the interface between ecology and social sciences is three-fold (Fig. 2): (1) to understand whether urban biodiversity can create meaningful opportunities to reconnect people with nature (Miller, 2005); (2) to explore the efficiency of conservation education programmes in promoting people's capacity to experience biodiversity and (3) to investigate how the experience of biodiversity and its services affect people's lives and contribute to their conservation awareness. Such work is essential for identifying sustainable solutions that can benefit both people and conservation (Fig. 2).

3.1.3. Research priorities regarding the scope of urban conservation studies

Our results confirm three important biases in urban conservation research that can affect how urban environments are valued for conservation. The first is a geographical bias. The studies were conducted in 58 countries (Fig. 3) and unsurprisingly, the observed distribution of papers per country was significantly different than the expected number of papers based on the land cover of urban area of each country ($\chi^2 = 1432$, $df = 57$, $p < 0.001$). In several countries, urban conservation research was strongly over-represented compared to the urban cover: Finland (14 papers vs. 1.08 expected), Singapore (7 vs. 0.61), Sweden (27 vs. 3.22), Australia (103 vs. 15.71), New Zealand (12 vs. 1.86) and Switzerland (9 vs. 2.15). In accordance with previous reviews of geographical bias in ecology (Martin et al., 2012) and urban wildlife studies (Magle

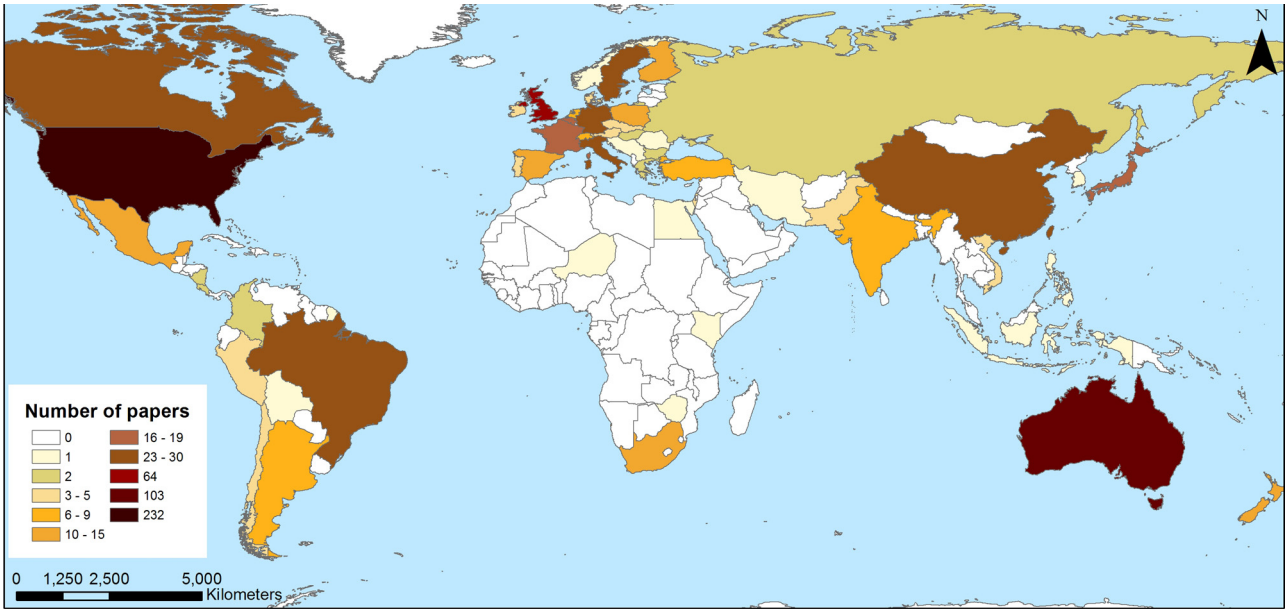

Fig. 3. The distribution of the number of studies reviewed for each country.

et al., 2012), we found that 79% of the reviewed studies were conducted in Europe, North-America and Oceania, out of which 69% in Anglo-Saxon countries (Table 3, Fig. 3). These results highlight a major concern: the existing scientific knowledge on urban conservation is strongly based on research in the developed countries, while the urgent need lies in those countries which face rapid urbanization process (McKinney, 2010; Magle et al., 2012). More than 95% of the future net increase in global urban population is expected to occur in Asia, Latin-America and Africa (McKinney, 2010). In these regions, potential urban development is also closely located to biodiversity hotspots (Cincotta et al., 2000). It is thus not clear to what extent the existing knowledge is relevant for managing urban biodiversity in those rapidly developing countries. Green spaces could provide different types of co-benefits in these countries. Interestingly, the five studies in our review that showed that the urban environment can provide resources for inhabitants were conducted in Asia, South-America and Africa. The challenge is therefore to explore the role that different motivations play in those biodiversity-rich, rapidly developing regions, and how much of our understanding from previous research is useful there. However, in this review we only used English language search terms and although English is the main language of science today, we cannot overrule the hypothesis that the geographical bias we highlighted is a result of our English based literature searches.

The second major bias revealed by our review is that the majority of urban conservation studies focus on large (roughly >2 ha) green spaces (74%; Table 3). In European cities, Fuller and Gaston (2009) showed that green space cover represents 18.6% of the urban environment on average (range: 1.9%–46%). The number of papers studying large green spaces was significantly higher than the expected number, calculated based on the highest proportion of green space cover found in European cities (i.e., 46%; $\chi^2 = 335.83$, $df = 1$, $p < 0.001$). Although large green spaces are more likely to provide good conditions for effective conservation, Goddard et al. (2010) demonstrated that smaller green spaces can also have both social and conservation significance. Therefore, it is important to characterize the relative importance of different urban environments for biodiversity conservation. This direction is progressively being adopted; we found indeed a positive correlation between the publication year and the proportion of studies conducted in the urban matrix, i.e., residential and business areas (Pearson's $r = 0.82$). We agree that difficulties of access may hinder research in these private spaces. However, novel initiatives such as citizen science could offer a great opportunity, not only to explore the value of these private areas for conservation, but also to investigate how increasing ecological knowledge influences people (e.g., Cosquer et al., 2012).

Finally, a comparison of the distribution of taxa studied in urban conservation versus non-urban conservation research (Fig. 4) revealed significant differences ($\chi^2 = 93.17$, $df = 7$, $p < 0.001$). Similar to general conservation studies, three taxonomic groups are predominantly studied in urban conservation: invertebrates, plants and birds (Table 3). These results are slightly contradictory with a recent review showing bias towards vertebrate species, notably birds and mammals in urban studies (Magle et al., 2012), perhaps because these authors explored papers dealing with urban wildlife and not necessarily conservation. The share of papers

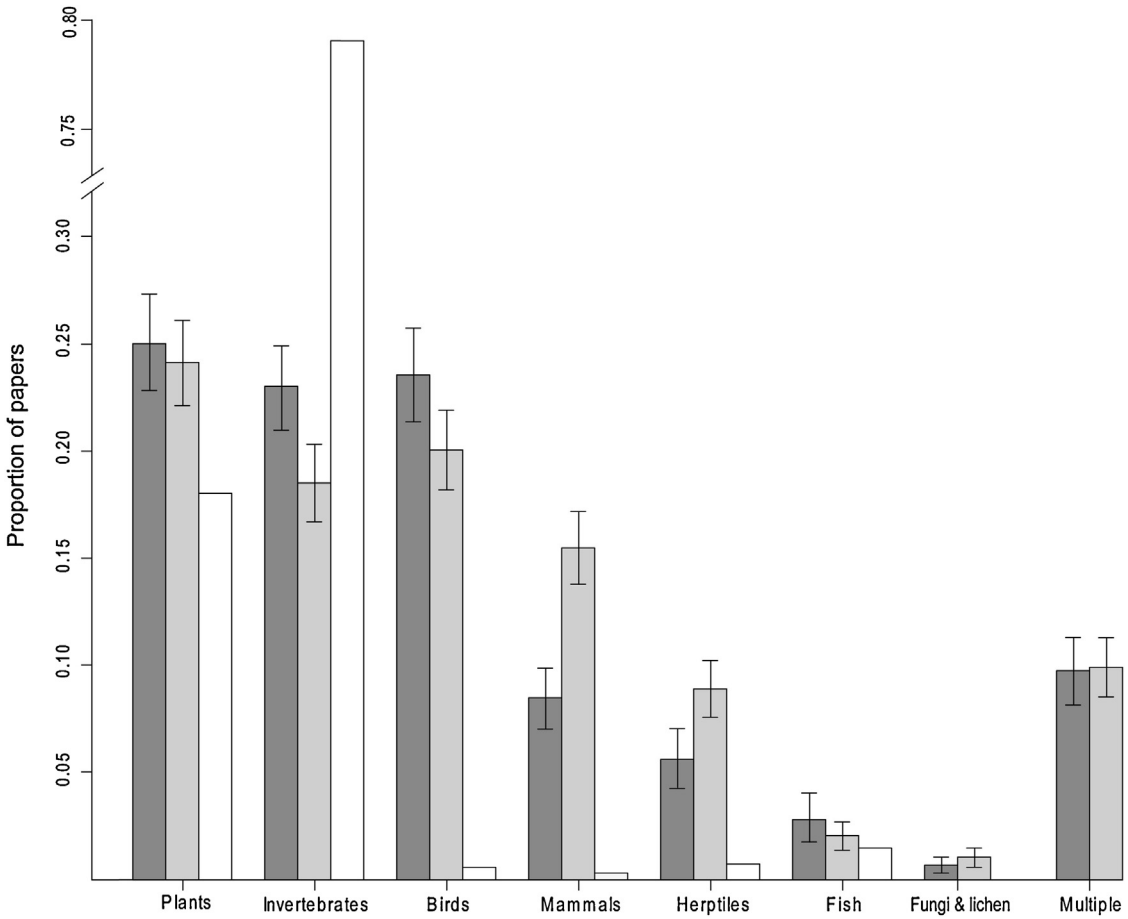

Fig. 4. Proportions ± SE are presented for the distribution of different taxonomic groups among urban conservation papers (dark grey), general conservation papers (light grey; Fazey et al., 2005) and their relative prevalence in nature (white, based on the number of known species; Clark and May, 2002).

studying plants (25%) was higher than the share of papers dealing with both plants in general conservation and the prevalence of plants in nature (Fig. 4). Invertebrate species, which are highly under-represented in general conservation studies in relation to their prevalence in nature, were comparatively better represented in the reviewed papers (Fig. 4). A recent study at a county-scale showed, for example, that urban areas have an added value for the conservation of arthropods because 13% of all species sampled were found only in the urban environment (Sattler et al., 2011). However, promoting invertebrate conservation in cities could lead to a conflict between conservation-oriented and people-oriented motivations because invertebrates are often negatively perceived by people (Hunter and Hunter, 2008).

3.2. Recommendations for policy-makers, planners and managers – a paradigm shift towards a co-benefit approach

Around the world, the movement for sustainable urban areas has been accompanied by a growing call for greener cities and for locally relevant ecological information and principles to guide urban development and management (McDonnell and Hahs, 2013; Felson et al., 2013). The present risk is that if the actions and policies used or promoted by practitioners and decision-makers are not backed up by science, they may have a negative rebound effect on biodiversity conservation. City-space is under high demand for many different types of uses, only some of which can contribute to nature conservation. Decision-makers are thus faced with practical questions about how much nature should be left inside the city, which type of nature, and how it should be distributed. But they have little solid scientific evidence (economic, environmental and social) to help them make their decisions. Our review provides some insights to these questions. For instance, we show that direct evidence demonstrating the role of urban biodiversity for broader conservation efforts, at landscape, regional and larger spatial scales are still poor. In contrast, urban nature may be more useful for conservation through the cultural services it provides, by contributing to people's quality of life. This has significant implications on the way biodiversity policies should be shaped in cities. The following recommendations are by no means prescriptive, but aim to help decision-makers and managers know where it is safe, given the current state of scientific knowledge, to expand their actions for biodiversity, and where this is more slippery. Since much of the research is based in developed countries care is required when adopting these principles for rapidly developing countries.

3.2.1. Enhancing urban biodiversity experience, not urban sprawl

Our comprehensive review revealed that the contribution of urban biodiversity to global biodiversity conservation appears limited, with only few examples showing the presence of viable target species (mainly plants and invertebrates) inside the city. Therefore, from a purely ecological perspective, current evidence does not warrant expansion of urban areas under green planning at the expense of more natural areas. Win-win situations for people and conservation may instead be found by enhancing the positive interactions between people and biodiversity within the existing urban boundaries, while accounting for other needs of city-dwellers (Irvine et al., 2013). Stepping stones and corridors, as well as appropriate management actions within the green spaces (e.g., Gaston et al., 2005; Shwartz et al., 2013) can substantially enhance biodiversity within the urban matrix. These tools can thus be profitably used by planners to enhance the biodiversity experience within the city.

Our review confirmed the results of extensive previous research (reviewed by Tzoulas et al., 2007; Keniger et al., 2013) showing that urban green spaces or nature contributes to improve people's well-being. Thus, green spaces encompassing at least some elements of nature are present in most cities. This represents an opportunity to avert what is known as the 'extinction of experience' from nature (Miller, 2005), since urban biodiversity increasingly represents people's first and main interaction with nature. If city-dwellers develop a knowledge or positive experience of biodiversity in cities, this is likely to affect their wider attitudes and eventually behaviours towards nature and biodiversity conservation (Prévot-Julliard et al., 2011). These behaviours include management and consumption choices (Schultz and Kaiser, 2012) or votes (Koger and Winter, 2010). Furthermore, cities also concentrate disproportionate parts of decision-making and financial resources in most countries. Increasing conservation awareness at the right levels could thus have large scale impacts on regional or global biodiversity conservation (McDonnell and Hahs, 2013). It could therefore be argued that urban planning and design have a role to play not simply in ensuring the provision of ecosystem services or improving people's well-being, but more deeply in bringing awareness about ecosystem processes and the services they can provide (e.g., Jordan et al., 2009). If managed and designed with this objective in mind, green spaces could indeed provide opportunities for incidental learning (Marsick and Watkins, 2001; Randler et al., 2007) on ecosystem functioning and processes. However, our review highlights that these hypotheses are not yet well supported and future work would benefit from being tied in with studies that explore the context and impact of these experiences (Cook et al., 2012).

3.2.2. Planning for the entire urban matrix

The urban matrix is characterized by a significant amount of green cover (Fuller and Gaston, 2009), composed by a mixture of public and private areas, which vary hugely in extent and quality. This review highlights that the majority of knowledge on urban conservation is derived from large (public) green spaces, such as parks and remnants. These large public green spaces combine a high potential for harbouring a rich diversity of both natural species and visitors thanks to the multiple uses they provide to city-dwellers (Irvine et al., 2013). They could thus be the hotspots where various people could experience nature on its complexity. However, recent studies have also demonstrated the importance of smaller private and public parcels in enhancing biodiversity, connectivity and people's interaction with nature (Goddard et al., 2010; Shwartz et al., 2014; Lindemann-Matthies and Marty, 2013). We therefore believe that a more holistic approach of the urban socio-ecological systems needs to be considered. Such an approach consists of efforts to improve the quality of all existing green infrastructures (private and public) to enhance the experience of biodiversity for people. Many local authorities already adopt biodiversity-friendly management for public green spaces and plan stepping stones or corridors that increase connectivity and thus local biodiversity (Shwartz et al., 2013). But they should also develop policies and campaigns promoting landowners to take similar actions. For instance, by encouraging the creation of green roofs or offering incentives to provide resources for biodiversity (e.g., nesting boxes) and encouraging campaigns for citizen-science monitoring programmes. These are just a few examples where local policies could help generate a positive feedback loop, whereby more biodiversity inside the city affects the use and demand for nature, and thus the uptake of green practices in urban planning and design.

3.2.3. Strengthening science-policy collaborations

Currently, practitioners and policy-makers are setting the pace in urban biodiversity conservation, which calls for rapidly closing the knowledge gaps (Fig. 2; McDonnell and Hahs, 2013). Fast progress could be made in these areas by initiating and actively

promoting science-policy collaborations (e.g., through grant application funding requirements) and science-practitioners interactions (e.g., in the design stages, Felson et al., 2013). Practitioners and policy-makers can keep contributing innovative solutions to provide city-dwellers with the opportunity to experience biodiversity, but they should also validate the efficiency of their initiatives.

4. Conclusions

The benefits of nature in cities are becoming clearer under global change and global urbanization. Urban areas across the world vary substantially in shape and form, but all contain some green spaces, and thus biodiversity within them. The broad picture suggests that urban ecosystems may only have limited direct conservation value (see also Kowarik, 2011), especially given the high price of land in cities. However, although the relationship between biodiversity and well-being remains complex (Dallimer et al., 2012), our results show that nature, green spaces and some species are valued by and essential for city-dwellers. Therefore, we argue that conservation in cities should be done primarily for and with people, maximizing their benefits, while seeking opportunities to conserve biodiversity. The challenge ahead is to understand how to shape the urban nature so that it can provide optimal benefits to people and biodiversity.

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