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Species richness in urban parks and its drivers: A review of empirical evidence

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Abstract There is growing recognition of urban areas as hosts for innovative ways to conserve and promote biodiversity. Parks, as one specific type of urban green space, constitute particularly important biodiversity hotspots in the cityscape. We reviewed empirical findings on the species richness in urban parks across all species groups that have been studied. The aim was to assess and discuss the overall species richness of urban parks, its community attributes and drivers. Search and subsequent selection process resulted in 62 papers from 25 different countries. For all examined species groups, the findings consistently show that parks are among the most species rich types of urban green spaces, but also that exotics constitute large shares, especially of plant species. Key ecological theories like the gradient approach and the island habitat ecological theory, and fundamental ecological relationships such as the species-area relationship are valid despite the manipulated 'nature' of parks and the surrounding urban matrix. Most studies surveyed large number of parks and applied 'multi-scale' approaches in tests of confounding variables, providing methodological strength. While matrix effects are consistently found to affect species richness negatively, the diversity of habitats and microhabitat heterogeneity contained in urban parks appears as the most decisive factor for the overall species richness. However, a constraint of research to date is the limitation of individual studies to one or a few species groups, rarely bridging between flora and fauna. Adopting 'multi-species group' approaches in future research is needed to further advance the understanding of the overall biodiversity of urban parks, and its drivers.

Keywords Biodiversity · Exotics · Fauna · Flora · Urban ecology · Urban green space

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Introduction

Biodiversity has been shown to hold a key role at all levels of the ecosystem service hierarchy (Mace et al. 2012). Efforts to mitigate global biodiversity loss have traditionally concerned large, bio-diverse and relatively untouched natural habitats and ecosystems (Lovell and Johnston 2009). Since urban development is strongly associated with the loss, fragmentation, and disturbance of habitats, parks and other green spaces existing within cityscapes have been regarded as unimportant (Atchison and Rodewald 2006). However, during the past decade research on urban biodiversity has become momentous–not only because of the increasing impact of urbanization on natural ecosystems, but also because of the growing recognition of urban areas as hosts for innovative ways to conserve and promote biodiversity (Savard et al. 2000) as suggested by various global environmental conventions such as the 2002 World Summit on Sustainable Development, the 2007 Curitiba Declaration on Cities and Biodiversity, and the Global Partnership on Cities and Biodiversity launched by among others the United Nations Environment Programme (UNEP 2012). Furthermore, enhancement of biodiversity in urban ecosystems can have a positive impact on the quality of life (Chivian and Bernstein 2004; Fuller et al. 2007; Hanski et al. 2012) and educate urban dwellers, thus ultimately facilitate the preservation of biodiversity also in natural ecosystems (Savard et al. 2000).

Research has documented that cities are disproportionally concentrated in areas with high ecosystem productivity and at junctions of ecosystems, both supporting high levels of naturally occurring biodiversity (e.g. Cincotta et al. 2000; Araújo 2003; Kuhn et al. 2004; Luck 2007). However, it is also well documented that the highly altered landscape of cities and the powerful, swift human-induced pressures are among the major threats to biodiversity (McKinney 2002; European Commission 2012). In other words, cities contain relatively high levels of biodiversity not because of, but rather in spite of urbanisation (Kuhn et al. 2004). This requires a perspective of cities as places with high potential for biodiversity conservation and promotion, but also places where biodiversity faces the greatest challenges (Farinha-Marques et al. 2011)

Multiple scales and spatial attributes interact in shaping urban biodiversity, and different and even contradictory results are frequently found across spatial scales. Therefore many researchers have emphasised the need to adopt a multi-scale approach in order to fully understand the interplay between the cityscape's matrix effects and the patch effects of urban parks and other green spaces (Savard et al. 2000; Angold et al. 2006; Werner and Zahner 2010; Lizée et al. 2012). The gradient paradigm has been widely applied to study changes along the urban–rural gradient (McDonnell and Pickett 1990) as have the island habitat ecological theory (island biogeography) for studies of related isolation/fragmentation effects (MacArthur and Wilson 1967). In addition analyses of the species-area relationships (Arrhenius 1921), native-exotic relationships (e.g. DeCandido 2004; Tonietto et al. 2011), and species-habitat quality relationships (e.g. Cornelis and Hermy 2004) are commonly applied.

While the concept of biodiversity embraces both the ecosystem, the species, and the gene levels most research on urban biodiversity has focused on the species level, simply because it is well defined, quantifiable, and easily monitored (Farinha-Marques et al. 2011). In crowded, built-up urban environments species primarily find their habitats in open spaces dominated by vegetation and water. Parks, as one specific type of urban open space, have been shown to constitute particularly species rich hotspots in the cityscape (e.g. Cornelis and Hermy 2004; Li et al. 2006; Vilisics and Hornung 2009; Tonietto et al. 2011). Urban parks are here defined as delineated urban open spaces dominated by vegetation and water features, and generally reserved for public use. They are often larger than other urban green spaces, but can also have the shape of smaller ‘pocket parks’. They tend to be characterised by high levels of habitat diversity and microhabitat heterogeneity. As the diversity of animals and plants tends to correlate with habitat complexity and diversity (Cornelis and Hermy 2004) urban parks can therefore have a positive impact on biodiversity albeit their primary role is recreational.

While many different species groups of flora and fauna have been examined in urban parks, individual studies have generally been restricted to one or a few groups (Cornelis and Hermy 2004) implying that the findings and the practical applications suggested are restricted to the particular species group(s). In this review we expand the view beyond individual species groups, and compile, synthesise, and analyse empirical findings across all species groups that have been studied in urban parks. The aim of this work is to assess and draw broader conclusions about:

1) Overall species richness of urban parks compared to other types of green space
2) Community attributes of flora and fauna in urban parks with focus on native-exotic relationships
3) Patch and matrix effects on overall species richness in urban parks

Our review also aims to discuss methodological strength and weakness of research to date in regards of assessment of the overall species richness of urban parks and its underlying processes and drivers.

Methods

We restricted the review to studies reporting empirical data about species richness collected in open space areas located within cities and described by the authors as (urban) ‘parks’ as defined in the “Introduction”. We included sub-urban parks (e.g. Cornelis and Hermy 2004; Turner et al. 2005), semi-natural parks (e.g. Turner et al. 2005; Öckinger et al. 2009) and urban agricultural parks (Sorace 2001; Matteson and Langellotto 2010) thus encompassing a rather inclusive definition of urban parks. We also included studies where empirical data collected in urban parks were compared with data from other green space typologies in order to enable comparison of species diversity. Studies reporting data from undefined urban green, or vegetation surface cover, or entirely from green spaces other than urban parks were beyond the scope of this review. Similar to McKinney (2008) we focus on species richness and omit species abundance, because the studies where abundance is included in diversity metrics tend to yield the same patterns.

Search strategy

The literature search was conducted from February 2012 to April 2012. Farinha-Marques et al. (2011) observed that few pre-year 2000 publications seemed to exist on aspects of urban ecology and urban biodiversity, but from then on, more studies started being published. Accordingly, the search was restricted to studies published from 2000 to April 2012 in the two major scientific databases Scopus and Web of Science.

Aiming for high sensitivity, consequently resulting in relatively low search specificity as recommended by Pullin and Stewart (2006) the search was restricted to the following combination of keywords: “urban park*” OR “city park*” OR “green space*” OR “green area*” AND “biodiversity” or “species richness” (* indicating wild card, i.e. any ending possible) .

The search terms were considered among topic, title, keywords and abstract. When investigating and summarizing a broad and heterogeneous subject serendipity discoveries (such as finding a relevant paper when searching for something else, or by pursuing references of references) often proves important (Greengalgh and Peacock 2005), hence our scope was widened outside the protocol, e.g. by using "snow-balling". Titles and abstracts identified by the searches were scrutinized, and if fulfilling the inclusion criteria the entire article was retrieved. Studies meeting the inclusion criteria were:

- Published in peer-reviewed international journal
- Written in English
- Reporting empirical data about species richness collected in urban parks
- Published between 2000 and April 2012
- Available via the electronic databases Scopus or Web of Science

Data extraction and synthesis

For each study that meet the inclusion criteria, we extracted bibliographic information on (a) the geographical region in which the study was conducted, (b) the number of urban parks and other sites surveyed, if the information weas provided (c) the species group(s) investigated and most importantly (d) the findings with respect to species richness (and when possible community attributes), and (e) the confounding variables applied to test and explain the patterns and processes underlying the observed species richness.

Due to the heterogeneity between studies concerning species group(s) investigated, methodology and the reporting of data, quantitative synthesis and meta-analysis were not deemed suitable. Rather we applied qualitative synthesis and assessments, as also applied in other reviews of urban biodiversity (e.g. McKinney 2002; Farinha-Marques et al. 2011) and reviews focusing on particular species groups (e.g. Fernandez-Juricic and Jokimäki 2001; Hernandez et al. 2009).

Results

The search generated 266 hits in Scopus and 175 hits in Web of Science. After screening of title and abstracts 66 potentially eligible papers were retrieved from Scopus and 56 from Web of Sciences. However, several of the papers overlapped between the two databases. Eventually 62 papers were included in the review (28 identified through the Scopus search, 15 through the search in Web of Science, and 19 from both).

Bibliographic overview of studies

Of the 62 papers included in the review, 32.3 % (n=20) presented studies conducted in Europe, 30.6 % (n=19) work in Asia (incl. Israel), 21.0 % (n=13) in North America, 8.1 % (n=5) in South America (incl. Mexico), and 6.5 % (n=4) in Australia and New Zealand, while one study of ants involved data from Japan, Canada and several European countries (Magura et al. 2010). Noticeable, the search did not identify any study from Africa. In all, empirical data had been collected from urban parks in 25 different countries.

From 52 of the papers it was possible to extract information about the number of parks and other sites included in the data collection, while the remaining 10 papers were reviews (e.g. Hernandez et al. 2009) and studies where we were not able to distinguish the exact number of parks surveyed (e.g. Chamberlain et al. 2007; Smith 2007). In total 1284 sites were surveyed in these 52 studies, of which 71.6 % (n=919) were described by the authors as (urban) parks. The remaining sites were forest remnants, street vegetation, derelict sites, private gardens, allotments, green roofs and different types of rural sites including nature reserves. On average each of the studies examined 24.7 sites of which 17.7 were parks. However, as shown in Fig. 1 and Table 1, the variation was substantial where the number of parks surveyed in the individual studies varied between 1 and 130 and resembled an exponential distribution.

As many as 47 studies (75.8 %) examined one species group only. Within these 40 studied one group of fauna (e.g. birds or butterflies), while seven examined one flora group exclusively (e.g. woody plants or bryophytes). Four studies (6.5 %) included two fauna groups (e.g. birds and butterflies), and 10 studies (16.2 %) examined vascular plants in general. Only four studies (6.5 %) examined both flora and fauna groups, all of which were conducted in Europe (see Table 1 for further information).

As shown in Fig. 2, birds were by far the most examined species group, being included in 48.4 % of the studies (n=30). Invertebrates and vascular plants were also fairly commonly studied, included in 30.6 % (n=19) respectively 27.4 % (n=17) of the studies. As mentioned above, seven of the studies of vascular plants were restricted to woody species. Butterflies and bees were especially well studied among the invertebrates with eight and five studies respectively. Most studies on butterflies were conducted in Europe while the majority of studies on bees were conducted in North America. By comparison, studies of mammals, amphibians, reptiles and bryophytes were limited in numbers.

Species richness of urban parks compared to other types of green space

In 14 studies (22.6 %) the species richness levels of urban parks were compared to other types of green space. In 64.3 % of these studies (n=9) urban parks contained more species than other types of urban green spaces (Fig. 3). This was true in two studies of birds (Kler 2006; Carbó-Ramírez and Zuria 2011) and one study of birds and mammals (Sorace 2001). For vascular plants Liang et al. (2008) found parks to be more species rich than green belts

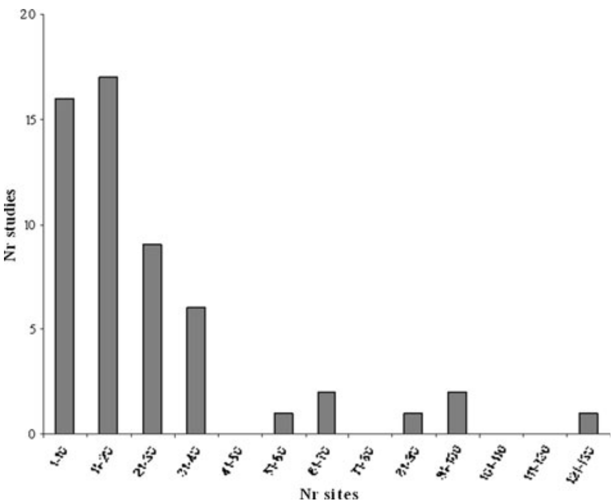

Fig. 1 Frequency groups for number of sites included in the empirical field work of the respective studies of urban park biodiversity

Table 1 Studies used as data sources for this review, with specification of (from left to right) country; species group(s) studied; patch and matrix variables included in the analysis; number of sites and parks surveyed. Patch effects related to habitat diversity, flora-fauna relationships, and specific habitats' are grouped as 'habitat qualities'

Author(s)	Country	Birds	Invertebrates	Mammals	Amphibian/ reptiles	Vascular plants	Woody plants	Bryophyte	Park vs. other sites	Native–exotic	Species-area	Isolation effects	Habitat qualities	Urban–rural	Nr of sites	Nr of parks
Bräuniger et al. (2010)	Germany	1	1			1		1			1	1			27	na
Hermy and Cornelis (2000)	Belgium	1	1	1	1	1									1	1
Cornelis and Hermy (2004)	Belgium	1			1	1					1		1		15	15
Gao et al. (2012)	Sweden	1		1		1							1		6	3
Lizée et al. (2011)	France	1	1											1	15	15
Forrest and St. Clair (2009)	Canada	1		1											1	1
Sorace (2001)	Italy	1		1					1						3	2
Carbó-Ramírez and Zuria (2011)	Mexico	1							1		1		1		19	6
Kler (2006)	India	1							1						13	4
Vallejo et al. (2009)	Philippines	1								1	1		1		4	2
Platt and Lill (2006)	Australia	1								1	1	1			12	12
Fitzsimons et al. (2011)	Australia	1								1	1				39	9
de Toledo et al. (2011)	Brazil	1								1		1	1		10	10
Imai and Nakashizuka (2010)	Japan	1								1		1	1		20	10
Shwartz et al. (2008)	Israel	1								1			1		1	1

Table 1 (continued)

Author(s)	Country	Birds	Invertebrates	Mammals	Amphibian/ reptiles	Vascular plants	Woody plants	Bryophyte	Park vs. other sites	Native–exotic	Species-area	Isolation effects	Habitat qualities	Urban–rural	Nr of sites	Nr of parks
Smith (2007)	Canada	1									1	1	1	1	28	na
Biaduń and Zmihorski (2011)	Poland	1									1		1	1	24	24
Oliver et al. (2011)	USA	1									1	1		1	20	20
MacGregor-Fors and Ortega-Álvarez (2011)	Mexico	1									1			1	5	5
Fernandez-Juricic (2000)	Spain	1									1	1	1		25	25
Chamberlain et al. (2007)	UK	1									1	1	1		277	na
Evans, K.L., Newson, S.E., Gaston, K.J.	UK	1									1	1	1		na	na
Fernandez-Juricic and Jokimäki (2001)	Europe	1									1		1		na	na
Khera et al. (2009)	India	1									1		1		19	19
Morrison and Chapman (2005)	USA	1									1		1		7	6
Murgui (2007)	Spain	1									1	1			130	130
MacGregor-Fors (2008)	Mexico	1											1		8	3
Lin et al. (2008)	Taivan	1											1		17	17
Atchison and Rodewald (2006)	USA	1												1	36	36
Murgui (2009)	Spain	1												1	na	na

Table 1 (continued)

Author(s)	Country	Birds	Invertebrates	Mammals	Amphibian/ reptiles	Vascular plants	Woody plants	Bryophyte	Park vs. other sites	Native–exotic	Species-area	Isolation effects	Habitat qualities	Urban–rural	Nr of sites	Nr of parks
Pacheco and Vasconcelos (2007)	Brazil		1						1	1	1	1	1	1	17	2
Tonietto et al. (2011)	USA		1						1	1		1	1		18	6
Vilisics and Hornung (2009)	Hungary		1						1	1					100	18
Öckinger et al. (2009)	Sweden		1						1		1	1	1	1	20	12
Koh and Sodhi (2004)	China		1						1			1	1		39	20
Hernandez et al. (2009)	USA		1								1	1		1	na	na
Konvicka and Kadlec (2011)	Czech Rep.		1								1			1	25	4
Yamaguchi (2004)	Japan		1								1	1	1		98	98
McFrederick and LeBuhn (2006)	USA		1								1	1	1		18	18
Lizée et al. (2012)	France		1								1	1			24	24
Clarke et al. (2008)	USA		1								1				24	24
Matteson and Langellotto (2010)	USA		1									1	1		18	18
Emery and Emery (2004)	Australia		1										1		3	3
Smith et al. (2006)	UK		1										1		11	4
Magura et al. (2010)	3 continents		1											1	9	3
Kitahara and Fujii (1997)	Japan		1												3	3

Table 1 (continued)

Author(s)	Country	Birds	Invertebrates	Mammals	Amphibian/ reptiles	Vascular plants	Woody plants	Bryophyte	Park vs. other sites	Native–exotic	Species-area	Isolation effects	Habitat qualities	Urban–rural	Nr of sites	Nr of parks
Mahan and O'Connell (2005)	USA			1									1		8	7
Vignoli et al. (2009)	Italy				1						1		1	1	62	na
Liang et al. (2008)	China					1			1			1	1		63	15
Li et al. (2006)	China					1				1	1		1		24	24
Säumel et al. (2010)	Europe					1				1					11	11
Zhao et al. (2009)	China					1				1					53	53
DeCandido (2004)	USA					1							1		1	1
Turner et al. (2005)	Canada					1			1	1					17	4
Jim and Liu (2001)	China						1		1	1	1				35	21
Jim and Chen (2009)	China						1		1				1	1	32	10
Jim (2004)	China						1						1		na	na
Jim and Chen (2008)	China						1		1						30	10
Nagendra and Gopal (2011)	India						1			1			1		40	40
Chen and Jim (2010)	China						1								na	na
Stewart et al. (2004)	New Zealand						1								89	89
Oishi (2012)	Japan							1	1				1		4	1
SUM		30	19	5	3	10	7	1	14	15	28	20	34	14		

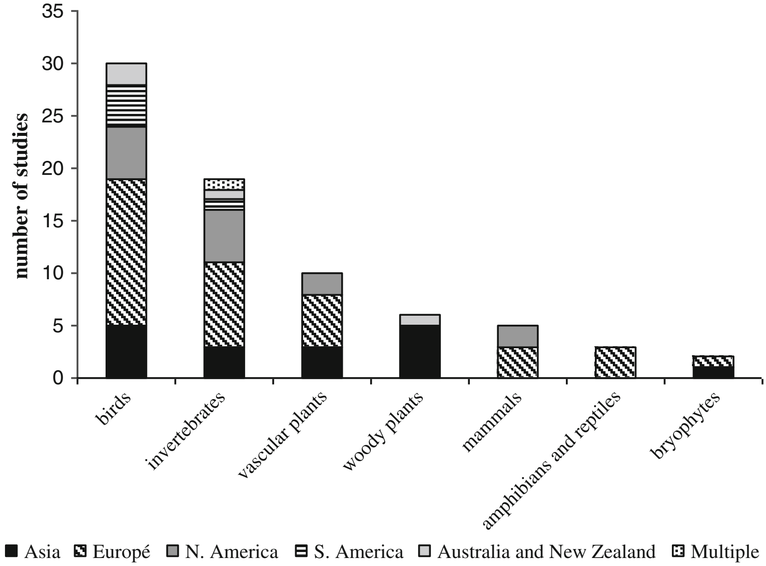

Fig. 2 Categorization of empirical studies of biodiversity of urban parks according to species group(s) investigated and geographical region in which the study was conducted. When individual studies have investigated more than one species group, the groups have been listed separately. Asia here includes Israel, and South America includes Mexico

and streets in Beijing while Turner et al. (2005) found vascular plant species richness was higher in residential neighbourhoods than in forest plots within semi-natural urban parks in Halifax, Canada. For woody plants two out of three studies of plants found parks to be the more species rich than riverside green space and street niches (Jim and Chen 2008, 2009). However, in a study of tree species diversity in Guangzhou, China institutional grounds

Vilisics and Hornung (2009)	Old gardens	Urban woodland	Isopod species	City center	Natural woodland	Younger gardens
Öckinger et al. (2009)	Semi-natural grassland	Urban ruderal sites	Butterflies			
Koh and Sodhi			Butterflies	Urban wodland		
Tonietto et al. (2011)		Prairie	Bees	Green roofs		
Pacheco and Vasconcelos (2007)		Nature reserve	Ants	Residential area	Commercial area	
Sorace (2001)			Birds and mammals	Peri-urban arable area		
Kler (2006)			Birds	Residential areas	Religious places	Market places
Carbó-Ramírez and Zuria (2011)			Birds	Gardens	streets	
Oishi (2012)		Japanese garden	Bryophytes			
Jim and Chen (2008)			Woody plants	River site green space	Street verges	
Jim and Chen (2009)			Woody plants	River site green space	Streets	
Jim and Liu (2001)		Institutional ground	Woody plants	Road side niches		
Liang et al. (2008)			Vascular plants	Green belts	Streets	
Turner et al. (2005)		Residential areas	Vascular plants			
			Urban Parks			

Fig. 3 Relative species richness levels of urban parks compared to other site types, with decreasing diversity from left to right. Urban green spaces are to the right of the *black line* and semi-natural and natural areas in the rural areas are to the left. The *grey filling* indicate the urban green space type with highest species richness. The column with names of species group(s) indicate the position of urban parks and the species group(s) in focus of the individual studies

contained more species than parks (Jim and Liu 2001). For invertebrates Pacheco and Vasconcelos (2007) found that parks represented the urban green space type that represented highest species diversity of ants in the city of Uberlândia, Brazil, but the species richness in urban parks was lower than in nature reserves. Tonietto et al. (2011) found that parks in Chicago contained more bee species than other types of urban green space, and nearly the same levels as undisturbed prairies. However, for isopod species in Budapest, the species richness in urban parks was lower than in old gardens and urban woodlands (Vilisics and Hornung 2009). For butterflies, however, Koh and Sodhi (2004) found that those urban parks in Singapore that had adjoining forest had a higher number of species and abundance than forest remnants, while Öckinger et al. (2009) identified that both species richness and density of butterflies were higher in ruderal sites within Malmö, Sweden than in traditional and semi-natural parks. For bryophytes, Oishi (2012) concluded that species richness was higher in a Japanese garden compared to an urban park in the city of Kanazawa, Japan.

Native-exotic relationships in urban parks

Information about the relative distribution between native and exotic species explicitly in urban parks could be extracted from 24.2 % of the studies (n=15). Seven of these concerned flora groups and nine examined fauna groups (Fig. 4). Synthesis of the studies of plants show that exotics accounted for a mean of 41.8 % of woody species in urban parks (variation between 6.2 % and 66.3 % in three studies) and 42.6 % of all vascular plants in urban parks (variation between 17.2 % and 66.0 % in four studies). A longitudinal study of Pelham Bay Park in New York City by DeCandido (2004) demonstrated a negative trend with as much as

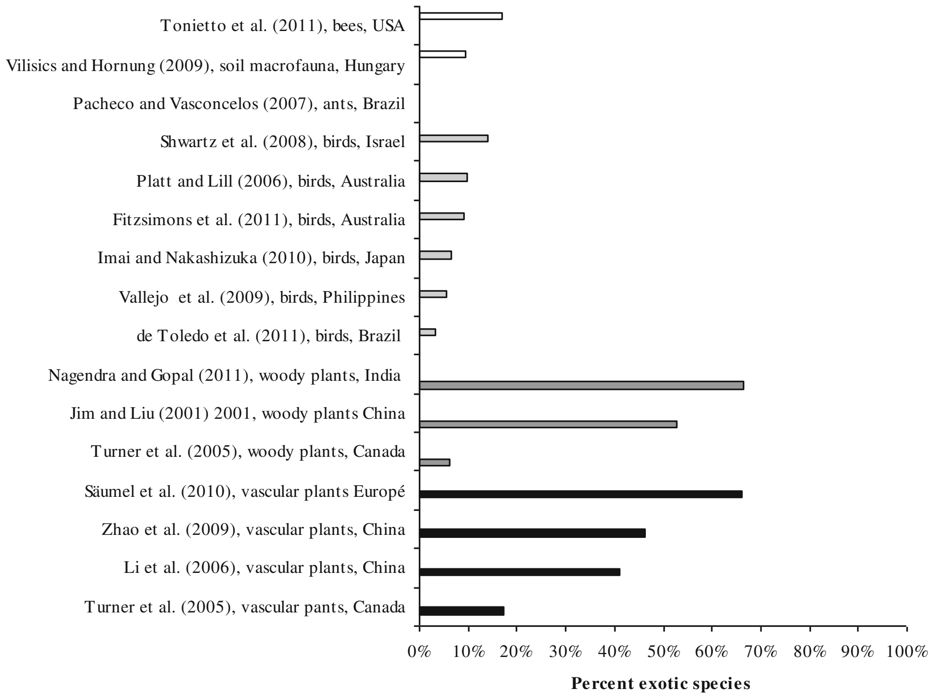

Fig. 4 Share of exotic species of total species in parks: vascular plants (*black*), woody plants (*dark grey*), birds (*light grey*), invertebrates (*white*)

25.5 % of the park's native species being extirpated from 1947 to 1994; a rate of 2.9 species lost per year. This was partly due to competition from exotic species which showed an increase of 39.7 % during the study period. Native herbaceous species were significantly more likely to be extirpated than native woody species, and herbaceous species of meadow-type habitats were more likely to be extirpated than species found in woodlands.

As shown in Fig. 4 studies of fauna species groups in urban parks generally reported exotics to account for lower shares compared to those reported for plants. Six studies examined the relationships for birds. They reported between 3.1 % and 14 % of the sighted bird species to be exotics, with an average of 8.1 %. Also for birds, a longitudinal study by Biaduń and Zmihorski (2011) demonstrated negative trends. In their study of 24 parks in Lublin city, Poland they found a loss of 0.2 bird species and 2.3 territories per year from 1982 to 2007. For invertebrates, Tonietto et al. (2011) found that 17 % of the bee species observed in urban parks of Chicago were exotics. Vilisics and Hornung (2009) reported 9.6 % of the soil macrofauna in urban parks of Budapest, Hungary, to be exotics, while urban parks within the city of Uberlândia, Brazil, were apparently free of exotic ant species (Pacheco and Vasconcelos 2007).

Patch effects on species diversity of urban parks

While comparison of species richness between urban park and other types of green space and studies of exotics and native relationships in urban parks were well distributed between flora and fauna species groups, analysis of confounding patch effects related to park size and habitat qualities were nearly entirely restricted to fauna groups (Fig. 5).

Species-area relationship

One of the most fundamental ecological relationships concerns the relation between an increase in available area for habitation and increase in species richness (Arrhenius 1921). We found 28 studies (45.2 %) investigating the effect of park size on the diversity of one or several plant, and especially animal groups. Synthesis of results from these studies

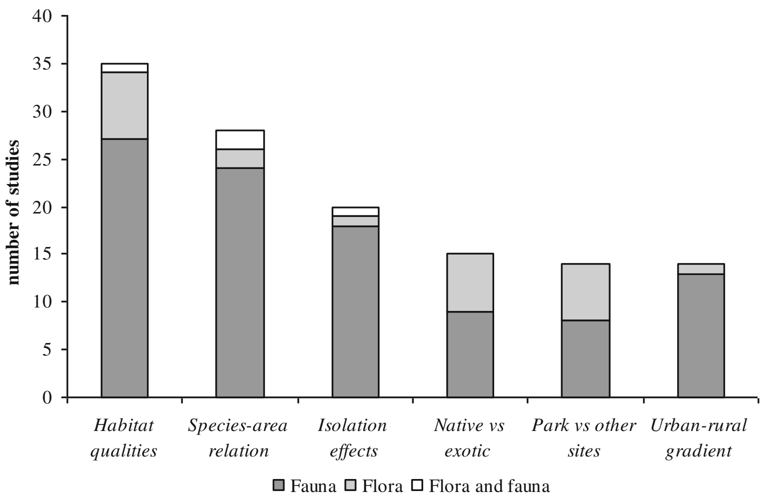

Fig. 5 The most common variables applied in analyses as predictions of observed fauna (*dark grey*), flora (*light grey*) and flora and fauna diversity (*white*) in urban parks. Patch effects related to habitat diversity, flora-fauna relationships, and specific habitats' are grouped as 'habitat qualities'

demonstrates that the species-area relationship is valid also for urban parks. In a comprehensive study of species groups selected to reflect different dispersal abilities of flora and migration and territory requirements of fauna, Bräuniger et al. (2010) concluded that size of urban parks and protected areas in Halle/Saale city, Germany was the most important factor for total species richness of lichens, mosses, vascular plants, birds, butterflies, carabid beetles and snails. Park size was also identified as one of the most important factors for the diversity of different groups of invertebrates (six out of nine studies), plants (five studies), amphibians and reptiles (two studies), and mammals (one study).

The species-area relationship has been particularly well studied for birds where 17 out of 18 studies found positive correlations and documented a nested pattern, where large parks harbour all the species present in small parks besides those that are only found in large ones (Platt and Lill 2006). Studies in Ontario, Canada (Smith 2007) Rovaniemi and Oulu, Finland; Osaka, Japan; Madrid, Spain; Springfield, USA; Bratislava, Slovakia; and several cities in Poland (Fernandez-Juricic and Jokimäki 2001) and the Greater London (Chamberlain et al. 2007) have consistently identified a threshold size after 10 ha. In the only study that did not find a positive relationship between park size and bird species richness, the five parks surveyed were all similar in size or larger (11.73 to 71.71 ha) than this threshold size (MacGregor-Fors and Ortega-Álvarez 2011).

Habitat diversity

The empirical research shows that part of the species-area relationship is due to larger parks tending to harbour a greater habitat diversity and microhabitat heterogeneity than smaller ones (e.g. Fernandez-Juricic and Jokimäki 2001; Cornelis and Hermy 2004; Smith 2007; Khera et al. 2009). Cornelis and Hermy (2004) concluded that the number of habitat units, the number of plant species and amphibian species all increased with increasing park area, and could even be predicted based on park area. All studies that tested the effect of habitat diversity found a positive relationship between increased diversity of habitats and increased species richness. Carbó-Ramírez and Zuria (2011) showed that this relationship was also valid for 'pocket parks' (0.1–2 ha) in Pachuca city, Mexico.

As shown in Table 2, many studies also examined the relationship between species richness and individual habitat types/qualities in urban parks. Water bodies and complexity and age of woody vegetation emerge as beneficial for bird species richness across several studies and for invertebrates the research provide some evidence that rough herbaceous vegetation and floral diversity is favourable. Preferences of other species groups have been much less researched in studies of urban parks.

Flora-fauna relationship

In nature the number of animal species tends to correlate with the number of plant species in an area (Savard et al. 2000; McKinney 2002). The reviewed literature indicates that this relationship is also valid for urban parks. In their comprehensive study, Bräuniger et al. (2010) found, that vascular plant species richness, including natives, archaeophytes (pre 1500 AD exotics) and neophytes (post 1500 AD exotics) was the best predictor for total species richness of urban parks and protected areas within Halle/Saale city, Germany. However, the relationship is only well documented for birds and species diversity of woody vegetation, where bird species richness exclusively have been found to respond positively to increased species richness of woody vegetation across six studies (Khera et al. 2009; MacGregor-Fors 2008; Shwartz et al. 2008; Evans et al. 2009; Biaduń and Zmihorski 2011; de Toledo et al.

Table 2 Positive relationship between specific habitat qualities of urban parks and species richness of birds, invertebrates, mammals, amphibians/reptiles

	Birds	Invertebrates	Mammals	Amphibians/ reptiles
Woody plant species richness	Carbó-Ramírez and Zuria (2011)	Koh and Sodhi (2004)		
	de Toledo et al. (2011)			
	Evans et al. (2009)			
	Fernandez-Juricic and Jokimäki (2001)			
	Khera et al. (2009)			
	MacGregor-Fors (2008)			
	Shwartz et al. (2008)			
Remnant vegetation	Vallejo et al. (2009)	McFrederick and LeBuhn (2006)		
Tree age/size	Biaduń and Zmihorski (2011)	Yamaguchi (2004)	Gao et al. (2012)	
	Carbó-Ramírez and Zuria (2011)			
	Fernandez-Juricic (2000)			
	Fernandez-Juricic and Jokimäki (2001)			
	Gao et al. (2012)			
	MacGregor-Fors (2008)			
	Shwartz et al. (2008)			
Dead wood	Morrison and Chapman (2005)			
Structure and complexity of woody vegetation	Carbó-Ramírez and Zuria (2011)		Gao et al. (2012)	Vignoli et al. (2009)
	de Toledo et al. (2011)			
	Evans et al. (2009)			
	Fernandez-Juricic and Jokimäki (2001)			
	Gao et al. (2012)			
	Imai and Nakashizuka (2010)			
	Khera et al. (2009)			
Native plant species	Chamberlain et al. (2007)	Pacheco and Vasconcelos (2007)		
	de Toledo et al. (2011)			
	Fernandez-Juricic and Jokimäki (2001)	Tonietto et al. (2011)		
	Khera et al. (2009)			
Water bodies	Chamberlain et al. (2007)		Mahan and O'Connell (2005)	Vignoli et al. (2009)
	Fernandez-Juricic and Jokimäki (2001)			

Table 2 (continued)

	Birds	Invertebrates	Mammals	Amphibians/ reptiles
	Imai and Nakashizuka (2010) Lin et al. (2008) Shwartz et al. (2008) Smith (2007) Vallejo et al. (2009)			
Rough herbaceous vegetation/floral abundance	Carbó-Ramírez and Zuria (2011) Chamberlain et al. (2007)	Matteson and Langellotto (2010) Smith et al. (2006) Tonietto et al. (2011)		
Sunlight availability		Matteson and Langellotto (2010)		

The references indicate the individual studies where the relationship has been identified

2011). The studies also indicate that this relationship can be influenced both negatively and positively by the exotic plants species and their density. Thus, in a study of 19 parks and public green spaces in Delhi, India, Khera et al. (2009) found that bird species richness had a significant positive correlation with woody species richness but a negative relationship with increasing density of exotic woody species. Contrary, MacGregor-Fors (2008) found that almost all bird species sighted in the most species rich parks within a Mexican suburb used exclusively the Australian silk oak (*Grevillea robusta*), demonstrating that some exotic tree species can support bird diversity.

Park age

In natural ecosystems biotic succession increases the number of plant and animal species with time after disturbances, and among the studies 19.4 % (n=12) examined the influence of park age on the species diversity of plants (five studies), birds (five studies) and invertebrates (two studies). Synthesis of the results shows that changing design fashions and management levels imply that age of park has no general relationship with plant species richness (DeCandido 2004; Jim 2004; Li et al. 2006; Jim and Chen 2009; Nagendra and Gopal 2011). However, the same studies show that older urban parks have become important refuges for veteran trees, indicating that recreational and cultural values of urban parks can be combined with ecological values because they both are enhanced by retaining veteran trees (Jim 2004; Jim and Chen 2009; Nagendra and Gopal 2011). For example Jim (2004) found that parks in Guangzhou, China harboured as much as 22 % of all the city's heritage trees. Without exception the studies of relationship between park age and bird species diversity show that the presence of such old-growth trees in parks supports bird species richness because it allows birds with specific habitat requirements (urban avoiders) to make use of alternative niches and substrates not found in young parks (Fernandez-Juricic 2000; Fernandez-Juricic and Jokimäki 2001; MacGregor-Fors 2008; Biaduń and Zmihorski 2011; Gao et al. 2012). Biaduń and Zmihorski (2011) even found that tree age (as an indirect measure of park age) was more important for bird species richness than park area and degree of isolation in Lublin city, Poland. Also Fernandez-Juricic (2000) found that park age was a good predictor of habitat complexity and a better predictor of bird species richness in Madrid's urban parks than park size.

For invertebrates Yamaguchi (2004) found that increasing park age correlated positively with ant species richness in parks in Tokyo and Chiba, Japan. In comparison, Öckinger et al. (2009) found that both butterfly species richness and abundance in semi-natural parks in Malmö, Sweden, benefitted from early-successional stage habitats, and was only slightly lower than in semi-natural grassland remnants in the peri-urban agricultural landscape.

Matrix effects on species richness of urban parks

As was the case for patch effects, also test of confounding matrix effects on species richness of urban parks are nearly entirely restricted to fauna groups (Fig. 5).

Urban–rural gradient

Many of the studies included in this review rely on the urban–rural gradient approach, where environmental variation is assorted spatially along transects from inner city to surrounding, less-altered ecosystem. We found 14 studies (22.6 %) that applied the urban–rural gradient approach in analysis of confounding variables for species richness in urban parks (Table 1). Synthesis of these results echoes that native species diversity and density fade out as the distance from the city border increases, because urbanisation acts as an environmental filter that exclude species with specialised abilities or habitat requirements. This was true for birds, bees, ants, beetles, butterflies, and vascular plants. (Atchison and Rodewald 2006; Pacheco and Vasconcelos 2007; Smith 2007; Murgui 2009; Hernandez et al. 2009; Jim and Chen 2009; Vignoli et al. 2009; Öckinger et al. 2009; Magura et al. 2010; Biaduń and Zmihorski 2011; Lizée et al. 2011; Konvicka and Kadlec 2011; MacGregor-Fors and Ortega-Álvarez 2011; Oliver et al. 2011). However, in many of the studies this trend was masked by influx of exotic species and generalist species tolerating a wide range of habitat conditions, resulting in a stable number of species in parks along the gradient (e.g. Magura et al. 2010).

Isolation effects

The urban–rural gradient can also be regarded as a habitat-loss gradient (McKinney 2002) where parks and other green space often feature as more or less isolated 'green islands' in an 'urban ocean' of built up structure. Isolation effects occur when the urban matrix is impermeable to dispersal (Garden et al. 2010). Of the papers reviewed, 20 studied isolation effects. As much as 90 % of these (n=18) were restricted to one fauna species groups while Matteson and Langellotto (2010) examined the impact of park isolation on both bees and butterfly species richness.

With ten studies, effects of park isolation on species richness and assemblages, birds are again the most studied species group. Though the research has been conducted in different regions of the world (see Table 1) it consistently concludes that isolation influences urban bird species richness and assemblages negatively, but also that the effects of park size and habitat qualities override those of isolation in explaining bird species richness. In a study of 25 parks in Madrid, Spain, Fernandez-Juricic (2000) found that this was especially the case in older parks while isolation and other urban matrix effects were more pronounced in younger parks due to their lower habitat diversity and complexity.

Studies of the relationships between effects of park size and park isolation on invertebrate species richness report contradicting results. Across eight studies the effects of isolation were exclusively found to override park size as a predictor for species richness of ants, bees, and butterflies (Koh and Sodhi 2004; Yamaguchi 2004; McFrederick and LeBuhn 2006; Pacheco and Vasconcelos 2007; Hernandez et al. 2009; Öckinger et al. 2009; Tonietto et al. 2011; Lizée et al. 2012). However, as for birds Tonietto et al. (2011) identified habitat qualities to be more important than isolation in determining overall bee species richness and abundance in green roofs, parks, and remnant prairies in Chicago, USA. That park habitat qualities override isolation effects have also been reported for bumble bees in San Francisco's parks (McFrederick and LeBuhn 2006).

Only one study tested the isolation effects on the flora in urban parks, reporting a significant negative correlation between increased isolation and richness of vascular plant species in parks and other green spaces in Beijing (Liang et al. 2008). The study by Bräuniger et al. (2010) was the only one that bridged between flora and fauna groups. In their study of vascular plants, bryophytes, birds, bees, carbide beetles, and snails in parks and protected sites in a German city, patch size was the most important predictor for total species richness. But, after having corrected for effects of patch size isolation degree remained as a significant influence on overall species richness.

Discussion

Overall species richness and native-exotic relationships in urban parks

This review has collated empirical research on species diversity of all species groups that have been studied in urban parks, with the aim to assess and discuss the state-of-the-art of research on overall species richness of urban parks, as one particular important type of urban green space. The findings jointly point at parks as being hotspots within urban areas for all the species groups studied. When drawing results across the studies, it is clear that substantial components of native species can persist (e.g. Cornelis and Hermy 2004), but also that very large shares (often around 50 %) of the plants species found in urban parks are exotics, while natives constitute larger shares of fauna species groups. Similar results are reported for urban areas in general, where e.g. Liang et al. (2008) found that 47.65 of vascular plants in Beijing were exotics and Tait et al. (2005) identified that exotics constitute 54 % of plant species, 23 % of mammals, 7 % of birds, and 3 % of reptiles within the Adelaide metropolitan area, Australia.

As cities are centres of commerce, the large share of exotic plants is likely related to both accidental importations by traffic (trucks, planes and ships) and to intentional importation for cultivation. However, particularly in urban parks, landscape architectural fashions and related horticultural goals are often the main factor for the large share of exotic plants. When USA, Canada, Australia, New Zealand and Asia were colonised, European settlers applied the same landscape and planting design principles and often employed European species (Stewart et al. 2007). Parallel, species from the colonies were shipped back to Europe and used in parks due to their ornamental and 'exotic' qualities. For example, in a historical study of 11 parks from the 19th to 20th century along a gradient from Central to South-Eastern Europe, Säumel et al. (2010) found that exotics constituted as much as 66 % of the species on the planting lists. Also more recent park plantings have continued along this trend (Nagendra and Gopal 2011). While the introduction of exotic plants have enriched floristic diversity because introduction rates have outpaced native plant species extinctions (Mckinney 2008; Lososová et al. 2012) it contributes to an impoverishment of ecological integrity and adds to 'biotic homogenization', defined as the process of replacing localized native species with increasingly widespread non-native species, leading to increasing similarity between biotas of different areas (Lockwood and McKinney 2001).

The process of biotic homogenization in urban parks was clearly illustrated by the longitudinal study of vascular plants in Pelham Park, New York (DeCandido 2004). Similar results have been reported from studies at the city level. For example Godefroid (2001) found that the number of vascular plant species in Brussels, Belgium, did not change significantly between 1940 and 1994. However 9 % of the native species disappeared (n=58). By comparison 57 new exotic species arrived, leading to a dramatic increase in the number of exotic species (39.3 %). This is a particularly disturbing trend when coupled with findings from studies of the flora and fauna relationship, demonstrating that the increase of exotic plant species also has a negative impact of fauna groups, as e.g. observed in the study of the relationship between exotic woody vegetation and bird species richness in Delhi, India (Khera et al. 2009). This requires us to look at parks as species rich hubs within urban areas, but also recognizes that the striking component of exotic species, especially among plants, and many of the authors to the included studies argue for changed horticultural practices encouraging the use of native plants, while simultaneously using exotic species on the premise of ecological security, thus enriching plant diversity to the fullest (Liang et al. 2008; de Toledo et al. 2011; Nagendra and Gopal 2011).

Patch and matrix effects on overall species diversity of urban parks

Overall the review findings demonstrate that increased levels of urbanization along the urban–rural gradient and related isolation effects have a negative impact on the richness of all the fauna species groups studied and thus on the overall species richness of urban parks. Isolation of urban parks from other green space causes changes in the species assemblages towards more generalist species (urban exploiters and urban adaptors) and exotics, while specialist species and other area sensitive species (urban avoiders) fade out. These findings demonstrate the added value urban parks can have for biodiversity when they are interconnected with other green spaces as an integral part of a green infrastructure (European Commission 2012).

Research to date is less able to demonstrate how matrix effects interact with patch effects in shaping the overall species richness of urban parks. Results from ten studies of birds consistently showed that park size overrides isolation effects in determining bird species richness. In comparison, findings were equally consistent across eight studies that the relationship is the opposite for invertebrates. One reason for this disparity may be related to the territory required to maintain viable population sizes, where plants tend to require smaller areas than mammals and birds (vertebrates) with invertebrates having requirements intermediate between plants and vertebrates (Gaston et al. 1998; McKinney 2008). The opposing relationship between isolation and patch size effects on birds and invertebrate species richness identified through this review points to the need for studies that span several species groups in order to deepen the understanding of the relationship between park size and isolation in shaping the overall species richness.

This said the research demonstrates that the internal habitat qualities of urban parks are more decisive than both park size and park isolation for the richness and composition of both birds and invertebrates. This underlines the benefits of urban parks for urban biodiversity, regardless of the surrounding matrix effects. While the diversity of habitats and plant species contained in urban parks is largely rooted in aesthetic considerations and design fashions, the research provides evidence that it is mutually beneficial for biodiversity (Khera et al. 2009; Farinha-Marques et al. 2011). The opportunity for biodiversity promotion in urban parks related to conscious habitat design and management is therefore an interesting angle for future R&D projects to explore, not at least because the habitat qualities are largely within the control of park designers and managers. Since urban parks are so precious to and so frequently used by the urban dwellers their desired perceptions, and engagements must form an integral part of innovative habitat design and management approaches to conserve and promote biodiversity in urban parks (Elands and Van Koppen 2012).

Methodological strength and weakness of the research

Many of the included studies have investigated large number of parks, providing sound replications for statistical tests and generalisation of the findings at a local scale. The wide geographical coverage of the studies, including 25 countries on different continents, allows for further generalisation of the findings also to the global scale. Noticeable however, the review did not identify any research on this topic from African countries.

Many studies have adopted analyses and tests of confounding variables at different levels of spatial resolution. While this is also widely regarded as a methodological strength (Savard et al. 2000; Angold et al. 2006; Werner and Zahner 2010) the studies exclusively used an observational design which involved inventory and analysis of existing species richness and community attributes, rather than more controlled study designs such as experiments. This is not surprising given the types of intervention needed, which sets obvious limits to the feasibility of conducting experimental work. Nevertheless, given the absence of experimental research, drawing results across studies, as done in this review, becomes even more important to enable more general conclusions. In relation to this, the restriction of individual studies to one or a limited number of species groups that seldom bridge between flora and fauna constitutes an important limitation of research to date for assessment of the overall species richness of urban parks and its drivers. Among the included studies only Cornelis and Hermy (2004) and Bräuniger et al. (2010) provide rigorous assessments of total species richness of urban parks. The limited number of studies bridging across several species groups is likely to reflect the difficulties and costs associated with measurements of complete species assemblies of an area (Gaston 1996).

Conclusion

This review demonstrates that parks are among the most species rich types of urban green spaces for all species groups. Birds have been especially well studied and research on birds provides strong evidence across spatial scales. Future research could preferably aim to detail the understanding of other species groups. The results demonstrate that key ecological theories like the gradient approach and the island habitat ecological theory, as well as fundamental ecological relationships such as the species-area relationship are valid for urban parks, despite their manipulated ‘nature’ and surrounding cityscape. However, our compilation of findings demonstrates that the flora-fauna relationship should be used with caution as predictor for overall species richness in urban parks because of the significant shares of exotics. The large number of parks investigated in most studies and the wide geographical coverage of the studies, allows for generalisation of these conclusions at local as well as global scale.

The main constraint of research to date for assessment of the overall species richness of urban parks and its drivers is the limitation of individual studies to one or a few species groups rarely bridging between flora and fauna. Our review reveals that different and even contradicting findings are reported between species groups which complicate knowledge transfer to and sound decision making at the practical and policy levels. In regards for future research, adopting multi-species group approaches in individual studies could help to further advance the understanding of and evidence for the overall biodiversity of urban parks and its confounding variables. In addition coordination of study sites for future research on individual species groups can create important synergy effects that would enable more rigorous assessments of the overall species richness.

Research on biodiversity of urban parks has mostly focused on the threats and challenges for the conservation of biodiversity related to isolation, fragmentation, and other urban matrix effects. However, the empirical research provides evidence that the diversity of habitats and microhabitat heterogeneity contained in especially larger and older parks is the most decisive factor for their overall species richness and composition. The opportunities for biodiversity promotion in urban parks related to conscious habitat design and management therefore provide an interesting angle for future research that could contribute to the continued development of innovative ways to conserve and promote biodiversity in urban areas. This would especially be the case if initiatives are taken to develop an international network of urban parks (and other green spaces) for long-term and systematic studies. Existing and well established networks like the International Federation of Parks and Recreation Administration (IFPRA) would provide an obvious platform for initiation and coordination of such initiatives.

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