Biodiversity conservation in urban environments: a review on the importance of spatial patterning of landscapes

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Biodiversity conservation in urban environments: a review on the importance of spatial patterning of landscapes

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Abstract
It has been well established that biodiversity plays an irreplaceable role in ensuring the quality of human life through supporting ecosystem functions and services. As more and more people prefer to live in cities worldwide, biodiversity loss in urban environments is being increasingly reported more than ever before. This, in turn, may have a negative influence on the quality of human life in an urbanising world. Global research shows that the abundance and richness of fauna in urban environments depends, to a large extent, on the spatial patterning of different patches of urban vegetation such as urban forests, woodlands, parks, and gardens.
The principal aim of the research is to provide a coherent picture of the importance of spatial patterning and spatial ecology of wildlife species in urban environments. Based upon empirical data from North America, Latin America, Europe, Asia, Africa, and Oceania, the research involves a systematic review of international peer-reviewed publications relating to the connection between biodiversity and the composition and configuration of urban wildlife habitats. This review reveals the most important components of landscape pattern that contribute to the abundance and richness of urban wildlife species.
Ultimately, the results provide a deeper understanding of the strategic importance of spatial dimensions of landscape planning and management, in support of biodiversity conservation in landscapes that have already been widely affected by anthropogenic development. Importantly, the findings provide a set of spatially-explicit recommendations that can be strategically applied in urban landscape architecture and land use planning disciplines to help ensure that urban biodiversity is maintained in an era of climate change and rapid urbanisation.

Keywords:
Urban biodiversity; wildlife habitats; spatially-explicit landscape patterns; spatial ecology; landscape architecture

1. Introduction

The importance of biodiversity can be linked to the role of multiple services provided by the functioning of ecosystems. There is a positive relationship between biodiversity and ecosystem functions and services. Balvanera et al. (2006) analysed more than 400 measures of biodiversity effects on ecosystem services and suggested that biodiversity has positive effects on services provided by ecosystems under study. The meta-analysis by Cardinale et al. (2006) shows that biodiversity loss has negative effects on ecosystem functions in many different ways, and the connection between biodiversity and the functioning of ecosystems has been affirmed by others (Hector and Bagchi, 2007; Duffy et al., 2007; Duffy, 2008, Isbell et al., 2011; Hooper et al., 2012; Pasari et al., 2013; Tilman et al., 2014; Lefcheck et al., 2015). Ecosystem services, in turn, support different aspects of the quality of human life (Tzoulas et al., 2007; Pedersen Zari, 2015). These services have been classified as provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005). The first three services have direct effects on the quality of human life while the fourth supports other services. In an era of rapid urbanisation (Bashford, 2014) and climate change (IPCC, 1995), urban biodiversity is critically important to support the citizens' quality of life. Despite this, biodiversity is threatened by both urbanisation and climate change worldwide (McKinney, 2002; Parmesan, 2006). Grimm et al. (2008), for example, blame biodiversity loss on rapid urbanisation and climate change. They suggest, however, that both problems and solutions can be found in cities. Approximately 52% of the world's population live in cities while in some regions of the world this figure is higher than 80% (United Nations, 2008). This trend is estimated to continue over the coming decades (United Nations, 2014); more people are expected to live in urban environments and, consequently, more houses and infrastructures are inevitably required in order to respond to the increasing urban population. If managed inappropriately, urban development coupled with climate change impacts is likely to cause more widespread biodiversity loss and this, in turn, may affect the healthy functioning of ecosystems and accordingly the quality of human life in cities.

In response to this challenge, some researchers suggest that composition and configuration of patches of vegetation should be considered as a key vehicle in order for the landscape architecture discipline to respond to urban biodiversity loss. Spatial patterning of patches of urban vegetation is thought to hold the key to providing relatively suitable conditions for urban wildlife to remain in cities and support ecosystem services despite ongoing pressures on wildlife habitats imposed by urban development and climate change. The connection between landscape pattern and urban biodiversity can be interpreted under the pattern-process-relationship model in landscape ecology (Forman and Godron, 1986; Turner, 1989; Forman, 1995; Bell, 2001). According to this concept, patterns affect processes and vice versa at different scales (Forman, 1995; Botequilha Leitao and Ahern, 2002). Thus, change in each component of landscape pattern can affect urban biodiversity either directly or indirectly. Therefore, it seems imperative for landscape architecture researchers and practitioners to develop knowledge of what the most important components of landscape pattern composition and configuration are and how spatial patterning of urban green spaces may affect the presence, abundance and richness of urban wildlife species.

The principal aim of this research is to provide a coherent picture of the importance of spatial patterning and spatial ecology of wildlife species in urban environments in order for landscape architecture researchers and practitioners to build-up a deeper understanding of the most important components of landscape pattern that contribute to biodiversity in cities. This will help cities to support biodiversity where landscapes and wildlife habitats have already been widely affected.

2. Methodology

From November 2015 to February 2017, international literature was comprehensively reviewed using a wide range of available databases including ISI Web of Science, Science Direct, Springer Links, Scopus, Wiley Online Library, and Pro Quest Central. The aim was to address the following issues:

(1) To build up an in-depth understanding of pattern process relationship in landscape ecology science using seminal publications in the field;
(2) To develop an understanding of the role of landscape pattern composition and configuration in affecting wildlife species richness and abundance at the urban scale;
(3) To identify the most influential components of landscape pattern constructing and characterising urban wildlife habitats and their influence on the presence, richness and abundance of wildlife species.

A wide range of relevant keywords was used to retrieve a large number of publications. Keywords included, but were not limited to, *urban biodiversity*, *urban wildlife*, *urban bird diversity*, *urban wildlife management*, *urban zoology*, *urban avian diversity*, and *urban avifauna*. Keywords were searched both separately and accumulatively to find the most relevant published data. Publications retrieved were filtered to gather a limited number of the most preeminent and reliable ones. Google Scholar Citation Index and Journals' Impact Factors were utilised to examine the quality of publications. Both positive and negative citations were checked for the latest group of publications to ensure that the collection of the selected publications has the highest degree of validity and reliability. Next, the literature review was fulfilled in two stages as follows:

Stage 1: Given that landscape ecology science confirms that *pattern process* relationship is valid in various landscapes and different scales (Turner, 1989; Forman, 1995; Bell, 2001), seminal publications of international repute on the connection between biodiversity and landscape pattern composition and configuration were explored irrespective of scale of the studies (i.e. urban or regional).

Stage 2: Highly preeminent empirical research on the connection between biodiversity and landscape pattern composition and configuration at the urban scale was reviewed. Geographical diversity of the reviewed research was constantly controlled to ensure that the review considers the global scale and includes the diversity of climatic zones. Four criteria were taken into particular consideration in order to find the most relevant published data in this stage:

(1) Peer-reviewed, published from 2000 to the end of February 2017, written in English and indexed on online databases;

(2) Empirical-based, focused on the connection between landscape pattern composition and configuration and urban wildlife species richness and abundance on an urban scale;
(3) Received international attention, including a reasonable number of positive citations recorded on Google Scholar;
(4) Represented a local and/or regional picture of the current issues in the region under study.

Ultimately, fourty-one urban scale studies comprising empirical research in Africa (n = 2), Asia (n = 12), Europe (n = 9), Latin America (n = 6), North America (n = 5), and Oceania (n = 7) were selected for the final review representing a global perspective of the topic under study (Figure 1).

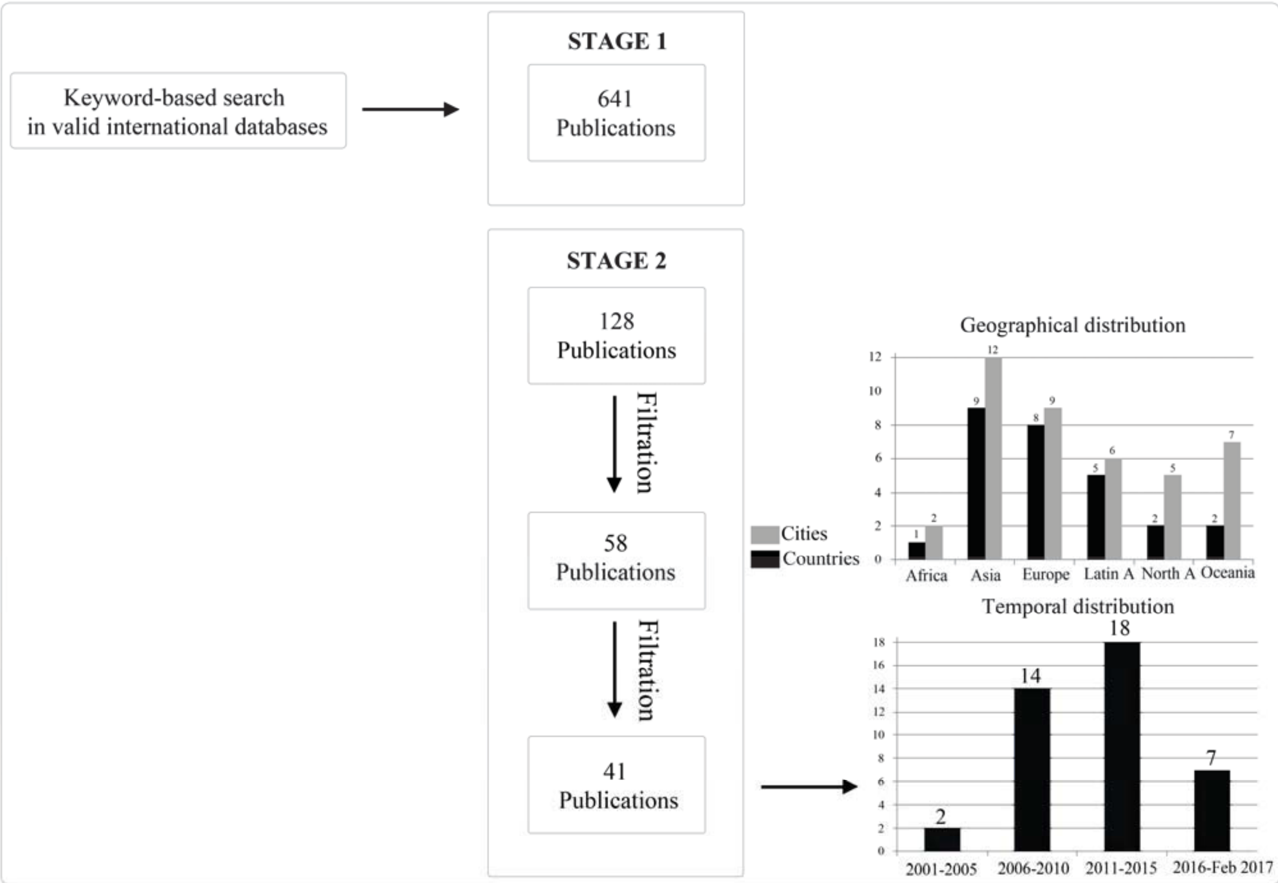

Figure 1. The multi-stage/criteria process undertaken to find the most reliable and relevant publications relating to the relationship between urban biodiversity and landscape pattern composition and configuration.

3. Results

3.1. Components of landscape pattern

Conceptual models (e.g. Island Biogeography Model (Mac Arthur and Wilson, 1967), Source-Sink Model (Pulliam, 1988), Patch-Corridor-Matrix Model, Forman, 1995), and the like) provide evidence that biodiversity is profoundly dependent on landscape pattern composition and configuration (Forman and Godron 1981; Forman and Godron 1986; Bridgewater, 1988; Turner, 1989; Soulé, 1991; Noss and Cooperrider, 1994; Forman, 1995; Murcia 1995; Dramstad et al., 1996; Collinge, 1996; Forman and Collinge, 1997; Savard, 2000; Noss, 2001; McGarigal and Cushman, 2002; Environmental Law Institute, 2003; Alberti, 2005; Botequilha Leitao et al., 2006; Farina, 2006; Opdam et al., 2006; Fischer et al., 2009; Haddad, 2009; Moorcroft, 2009; Heller and Zavaleta, 2009; Morrison et al., 2012; Walz and Syrbe, 2013). Landscape pattern is constructed and characterised by a number of components. From the literature reviewed, the most important components of landscape pattern affecting biodiversity are as follows:
(1) Indigenousness;
(2) Land cover heterogeneity;
(3) Land surface perviousness;

(4) Patch size;
(5) Connectivity and proximity;
(6) Edge density and contrast;
(7) Landform diversity;
(8) Shape complexity.

Taken together, the above-mentioned components of landscape pattern construct spatial characteristics of wildlife habitats, both in urban or non-urban environments. Change in any component of landscape pattern will have different implications for wildlife species richness and abundance. The components and their relationships with biodiversity are discussed in the following sections.

3.1.1. Indigenousness

Indigenousness is defined as the state of being indigenous (i.e. native) in terms of land cover type classes present in a landscape. Indigenous plants have an irreplaceable role in biodiversity – and thereby long-term ecosystem integrity in cities (Aronson et al., 2014; Rastandeh, et al., 2017). Forman (1995) suggests maintaining patches of indigenous vegetation, as small *bits of nature*, within human modified landscapes because of the services they provide as habitat and/or stepping stones for a wide range of wildlife species. Fischer et al. (2009) state that the overall level of biodiversity depends on the total number of indigenous plants present in a given landscape. The positive relationship between the percentages of indigenous vegetation and the extinction rate of indigenous plants has been confirmed in cities (Hahs et al., 2009).

3.1.2. Land cover heterogeneity

Land cover heterogeneity is defined as diversity of different land cover type classes in patch or landscape levels. The number of habitat types is positively related to biodiversity across landscape (Forman and Godron, 1986). Dramstad et al. (1996) argue that land cover diversity can contribute to biodiversity in different scales. Nielsen et al. (2013) reviewed 62 empirical research studies from 25 countries and pointed out that land cover heterogeneity may be the most important factor supporting urban biodiversity. In large scale, Fischer et al. (2009) affirmed that since species differ in their habitat requirements, diversity in land cover types in the same landscape can underpin suitable conditions for the presence and survival of different types of species. Botequilha Leitao et al. (2006) argue that some key ecological functions are affected by land cover diversity. They explain how richer diversity in forest and/or grassland land cover types can cause greater biodiversity. Reside et al. (2014) suggest that a wide range of habitats are required to maintain the long-term evolutionary process of species present across the landscape. Land cover heterogeneity can also give rise to a larger number of eco-tones where the number of wildlife species is thought to be high (Duelli, 1997).

3.1.3. Land surface perviousness

Land surface perviousness is defined as the ability of a particular land cover type or landscape to absorb run-off caused by rainfall, or sequester and store carbon dioxide in soil or vegetation. Some studies show that there is a positive relationship between land surface perviousness and bird diversity and abundance in urban landscapes. For example, Fernández-Juricic and Jokimaki (2001) demonstrate the negative correlation between bird species richness and paved ground within urban parks in Madrid, Spain. A study of three cities in Switzerland by Fontana et al. (2011) revealed that the percentage of land dominated by trees is the most important variable enhancing bird diversity in urban landscapes. A study of bellbird occupancy in Christchurch, New Zealand showed that the chance of bellbird presence is higher in unpaved urban surfaces covered by indigenous plants (MacLeod et al., 2012).

3.1.4. Patch size

Patch size is defined as the total area of a particular land cover type on a patch or landscape level. Other variables being equal, an individual large habitat can support more species because it is regarded as a large pool of species genes (Forman, 1995; Dramstad et al., 1996; ELI, 2003; Fischer et al., 2009). Large patches of vegetation are likely to contain more diverse species, thereby providing more widespread ecosystem services. Forman and Godron (1981) suggest that the size of patches present in a landscape affects productivity, nutrient and water flux, and species dynamics and, therefore, can be considered as an important indicator of biodiversity. Based upon MacArthur and Wilson (1967), they argued that when habitat diversity (i.e. heterogeneity) is equal in two patches of vegetation, the larger patch typically contains more species (cf. Forman et al., 1976; Forman and Godron, 1981).

3.1.5. Connectivity and proximity

Connectivity is defined as the spatial distance between patches of a particular land cover type. Spatial connectivity is believed to be vital to biodiversity (Naveh, 1994; Forman, 1995; Bennett, 1999). Spatial connectivity between patches of vegetation can facilitate the process of colonisation and, thereby, reduce the chance of plant species extinction (Shaffer, 1981; Honnay et al., 2003). The concept of planning urban and regional greenways that emerged in landscape architecture and regional planning (Ahern, 1995; Fabos, 2004; Toccolini, 2006; Turner, 2006; Walmsley, 2006; Mason, 2007; Teng et al., 2011; Palmisano et al., 2016) has been, to a large extent, a response to this ecological necessity. Some ecological processes and species, but not all, benefit from connectivity between patches including movement of species between habitats and the flux of energy and nutrients (Fischer et al., 2009). Connected patches in urban environments provide buffered corridors for species to migrate from one habitat to another to find food and shelter without facing unpleasant climatic conditions and urbanisation effects. Conversely, some researchers argue that connectivity can concurrently facilitate the dispersal of weeds and pests (Barnes, 2000; Botequilha Leitao et al., 2006; Sullivan et al., 2009).

3.1.6. Edge density and contrast

Edge density is defined as the perimeter of a patch of particular land cover type exposed to other land cover types. Edge contrast is also defined as dissimilarity between adjacent land cover types. Landscape fragmentation increases edge density (Andren, 1994). Both edge density (i.e. length) and edge contrast can affect urban biodiversity. As edge density increases, the patch interaction with its surroundings increases either positively or negatively (Dramstad et al., 1996). In a New Zealand context, Young and Mitchell (1984) and Davies-Colley et al. (2000) revealed that climatic edge effects are considerably reduced within c. 50 m and c. 40 m from the patch boundary, respectively. The former threshold has been suggested by Meurk and Swaffiled (2000) and Meurk and Hall (2006) to be regarded as a basis for edge effect analysis in New Zealand urban landscapes. This threshold has also been suggested by Murica (1995) after reviewing a comprehensive number of relevant publications, as well. In Australia, a 50 m edge width was recommended to design buffer zones for highly vulnerable large-size body species such as koala (Port Stephens Council, 2002). As wind and sun exposure widen edge effects (Dramstad et al., 1996), it is not, however, correct to assume that the width of edge effect remains the same around a patch.

3.1.7. Landform diversity

Landform diversity is defined as the diversity of elevations, slopes, and aspects. Landform diversity has been strongly suggested to safeguard biodiversity in the face of extreme events (Markham et al., 1993; Pernetta et al., 1994; Halpin, 1997). Research shows that temperature differences between south- and north-facing slopes can be considerable, ranging from 8°C to 12°C (Rorison et al., 1986; Ackerly et al., 2010). Landform diversity provides climate heterogeneity, and thereby safeguards more diverse species over time due to the diversity in environmental variables such as temperature, moisture and soil type in a heterogeneous topography (Noss, 2001; Fischer et al., 2009; Dobrowski et al., 2011; Reside et al., 2014). On an urban scale, diverse topography potentially provides diverse habitats for a wide range of urban species. On a fine scale (i.e. small urban parklands), however, research shows that landform diversity is less important to urban wildlife species (Cornelis and Hermy, 2004).

3.1.8. Shape complexity

Shape complexity is defined as the degree to which a wildlife habitat is dissimilar to a circle-shaped pattern. The proportion between edge-core areas in a given patch depends on patch shape affecting biodiversity (Noss and Cooperrider, 1994; Dramstad et al., 1996); however, the nature of impact may differ depending on the species under study. O'Neill et al. (1988) and Honnay et al. (1999) showed that patches with irregular shape contribute to richer plant diversity. At the same time, however, a wide range of animals may prefer compact shapes to protect themselves from the edge effects (Forman, 1995) because compact shapes decrease the odds of the penetration of negative environmental effects into the patch. Botequilha Leitao et al. (2006) depicted the relationships between patch shape, core area, and biodiversity and discussed how some characteristics are expected to occur in landscape when patch shape complexity increases and patch core area consequently decreases. They enumerated a range of events including an increase in the rate of evapotranspiration along patch edges exposed to sunlight and wind, an increase in the numbers and populations of exotic and predator species (and at the same time, a decrease in the presence of rare plant species that require specific patch interior conditions), a sharp reduction in the populations of ground-nesting songbirds due to predation pressure, and a decrease in storm-water storage in remnant patches of vegetation (Botequilha Leitao et al., 2006).

3.2. Empirical evidence in urban environments

Recently more attention has been paid to biodiversity and spatial ecology of wildlife species in urban environments (Müller and Kamada, 2011). The results of the literature review show an increasing trend in the number of publications on the relationship between spatial ecology of wildlife species and spatial composition and configuration of patches of vegetation in urban environments from 2001 to February 2017. Empirical evidence worldwide within a spectrum of different climatic zones (Peel et al., 2007) verifies that the presence, richness and abundance of urban wildlife species rely profoundly on spatial pattern of wildlife habitats scattered across urban environments. The selected publications are testimony to the role of the eight most important components of landscape pattern (indigenousness, land cover heterogeneity, land surface perviousness, patch size, connectivity and proximity, edge density and contrast, landform diversity, and shape complexity) in affecting a wide range of urban wildlife species including various butterflies, birds, reptiles, and mammals. The results derived from this stage of the literature review have been summarised to depict a global picture of the preeminent publications in peer-reviewed journals of international repute (Table 1).

Table 1: Selected international peer-reviewed publications based upon empirical data and field surveys from 2000 to February 2017 addressing the role of landscape pattern in affecting wildlife species in urban environments. Components involve: (1) indigenousness, (2) land cover heterogeneity, (3) land surface perviousness, (4) patch size, (5) connectivity and proximity, (6) edge density and contrast, (7) landform diversity, and (8) shape complexity. For additional information about climatic zones, see Appendix I.

Continent		City – Urban region	Climatic zone	Species under study	Components affecting species	Reference
North America						
	Canada	Southern Ontario	Dfa, Dfb, Dfc	Birds	1, 2, 4	Smith, 2007
	United states	St. Louis	Dfa - Cfa	Birds	2, 4	Oliver et al., 2011
		Boise	BSk	Birds	3	McClure et al., 2015
		Boston	Cfa	Birds	3, 4	Strohbach et al., 2013
		Baltimore	Cfa	Birds	3, 6	Rega et al., 2015
Europe						
	Belgium	Flanders	Cfb	Butterflies, birds, amphibians	1, 2, 4	Cornelis and Hermy, 2004
	Czech Republic	Prague	Cfb	Birds	1, 2, 5	Ferenc et al., 2014
	France	Marseille	Csa	Butterflies	5, 8	Lizee et al., 2012
	Germany	Halle	Cfb	Butterflies, birds, invertebrates	4, 6, 8	Bräuniger et al., 2010
	Spain	Madrid	Csa	Birds	2, 4, 6	Fernández-juricic, 2001
		Valencia	BSk	Birds	2, 3, 4	Murgui, 2009
	Sweden	Orebro	Dfb	Birds	1, 2, 5	Sandstrom et al., 2006
	Switzerland	Zurich, Lucerne, Lugano	Cfb	Birds	2, 3	Fontana et al., 2011
	United Kingdom	100 urban areas	Cfb	Birds	2, 4, 6	Evans et al., 2009
Latin America						
	Argentina	Mar del Plata	Cfb	Birds	3, 5, 6	Leveau and Leveau, 2016
	Bolivia	La Paz	Cwb	Birds	1, 3, 7	Villegas and Garitano-Zavala, 2010
	Brazil	Taubate	Cwa	Birds	1, 2	de Toledo et al., 2012
		Uberlandia	Aw	Invertebrates	1, 5	Pacheco and Vasconcelos, 2007
	Mexico	Pachuca	Cwb	Birds	2, 4, 6	Carbó-Ramírez and Zuria, 2011
	Venezuela	Margarita Island	Aw	Birds	1, 3, 5	Sanz and Caula, 2015
Africa						
	South Africa	Cape Town	Csb	Birds	5, 6	Calder et al., 2015
	South Africa	Cape Town	Csb	Birds	2, 5	Suri et al., 2017

Table 1: continued

Continent		City	Climatic zone	Species under study	Components affecting species	Reference
Asia						
	China	Yizhou	Dwa	Birds	2, 5	Yuan and Lu, 2016
	Japan	Sendai	Cfa	Birds	3, 6	Imai and Nakashizuka, 2010
	Hong Kong	Hong Kong	Cwa	Birds	4	Zhou and Chu, 2012
	India	New Delhi		Birds	1, 2, 4	Khera et al., 2009
	Israel	Tel Aviv	Csa	Birds	2, 3, 5	Shwartz et al., 2008
		Tel Aviv	Csa	Birds	1, 2	Paker et al., 2014
	Malaysia	Kuala Lumpur	Af	Butterflies	2, 4, 5	Sing et al., 2016
		Klang Valley	Af	Birds	4, 6	Aida et al., 2016
		Kuala Lumpur	Af	Birds	1, 3, 4	Jasmani et al., 2017
	Philippines	Manila	Aw	Birds	2, 4	Vallejo et al., 2009
	Singapore	Singapore	Af	Butterflies, birds	1, 3, 6	Chong et al., 2014
	South Korea	Seoul	Dwa	Birds	2, 4, 5	Kang et al., 2015
Oceania						
	Australia	Brisbane	Cfa	Reptiles, small mammals	1, 2, 3, 4, 8	Garden et al., 2010
		Canberra	Cfb	Birds	2, 3, 4	Ikin et al., 2013
		Melbourne	Cfb	Birds, bats	1, 2	Threlfall et al., 2016
		Melbourne	Cfb	Birds	4, 5	Platt and Lill, 2006
	New Zealand	Dunedin	Cfb	Birds	1, 2, 4, 5	vanHeezik et al., 2008
		Dunedin	Cfb	Birds	1, 3, 4	vanHeezik et al., 2013
		Christchurch	Cfb	Birds	1, 3, 5	MacLeod et al., 2012

4. Discussion

4.1. A more realistic approach

Although *making cities as green as possible* seems to contribute to urban biodiversity to some extent, implementation of this strategy may be unrealistic in practice because urban green space development requires enough space (i.e. suitable land) and sufficient funds. Beyond these factors, water shortage resulting from worldwide population growth and global warming is very likely to limit the goal of *making cities as green as possible*, specifically in countries where climate change affects water resources (IPCC, 1995; IPCC, 2014). Therefore, planning for biodiversity conservation in cities may differ in some cases from what planners undertake in natural areas. Knowledge of the spatial ecology of wildlife species, however, may help urban policy makers to make appropriate decisions on not only allocation of land to green spaces, but also spatial design of patches of urban vegetation (i.e. parklands, woodlands, and urban forests) in a way that supports wildlife species in urban environments where land availability is widely limited by socio-economic drivers.

4.2. Areas of conflict

This research also reveals that in terms of spatial patterning of patches of vegetation in urban environments, there are some areas of conflict between what wildlife species require and what humans expect from ecosystem services. First, although indigenous plants are necessary to ensure the continuation of biodiversity in urban environments, some exotic species may be socio-economically more acceptable to be used by land owners for carbon sequestration and storage (Ausseil et al., 2013; Ministry for Primary Industries, 2015; Setälä et al., 2016; McHale et al., 2017). In an era of climate change, conventional strategies may encourage people to plant exotic species to manage greenhouse gasses in cities through carbon sequestration. At the same time, research shows that some exotic flora may provide indigenous fauna with essential food during winters or initiate ecological succession towards indigenous plant communities (Rastandeh et al., 2017). Therefore, use of only indigenous plants in urban environments should not be considered as a clear-cut response to biodiversity loss because cities already contain non-indigenous plants, and these can be beneficial to urban ecosystems.

Second, while a higher rate of shape complexity and accordingly edge density may decrease the quality of wildlife habitats and consequently affect urban biodiversity, it can also reduce urban heat island effects through increasing the cooling effects of urban green spaces. A study of 21 urban parks in Addis Ababa, Ethiopia, for example, revealed that an increase in shape complexity and edge density may increase the park cooling distance – the range within which the cooling effect could be observed (Feyisa et al., 2014). This example is compatible with the results of a study conducted in the city of Aksu, China (Maimaitiyiming et al., 2014) where researchers showed that greater edge density resultant from higher shape complexity can effectively reduce land surface temperatures in urban environments without the need for increasing the total green space area. Similarly, a spatial analysis of land cover composition and configuration in the hot-arid city of Isfahan, Iran concludes that shape complexity (i.e. irregular, elongated, and convoluted configuration with enough core area) is negatively correlated with land surface temperature in urban environments (Asgarian et al., 2015; cf. Zhou et al., 2011; Kong et al., 2014; Park and Cho, 2016). Therefore, while compact patches of vegetation may benefit wildlife species through providing more core area and less edge, elongated ones may be more beneficial for people suffering from urban heat island effects.

Due to the coexistence of humans and wildlife species in cities, some ecosystem services may become contradictive in urban environments. Thus, the question of *high vs. low shape complexity* and consequently *high vs. low edge density* may remain an important issue of concern in landscape architecture research, particularly in the contemporary urban age when urban policy makers seek solutions to adapt cities and people to the local impacts of climate change. Therefore, a middle ground should be sought in order for landscape architecture researchers and practitioners to meet both wildlife species and human requirements. Such paradoxical functioning of ecosystems in non-urban environments is, however, unlikely because in natural landscapes planning is solely focused on wildlife conservation while in urban environments both wildlife species and humans must be taken into consideration in the process of planning patches of vegetation, and this in itself makes this process more complex and multi-dimensional (Figure 2).

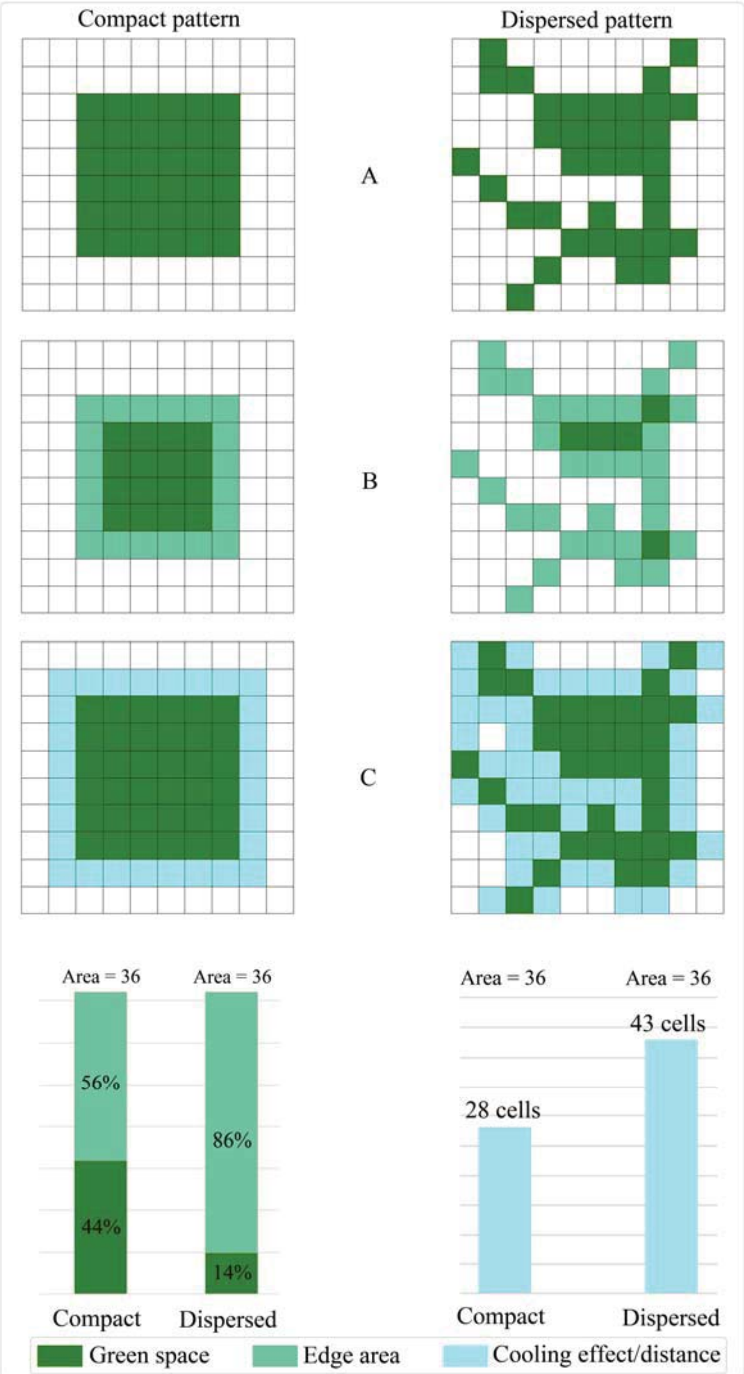

Figure 2. An example of areas of conflict between what wildlife species require and what people expect from spatial patterning of patches of vegetation in urban environments. Although green space area in both cases is equal (A), shape complexity, and thereby edge density, profoundly differs. The compact pattern is suitable for wildlife species to be protected from edge effects (B), whereas the dispersed pattern is more suitable for humans to mitigate urban heat island effects (C). In urban environments, there seems to be a need to seek a middle ground between what humans and wildlife species require in terms of spatial patterning of patches of vegetation.

4.3. A spatially-explicit perspective

Although planning for urban biodiversity is extremely site- and species-specific (Turner, 1989; Botequilha Leitao and Ahern, 2002; Botequilha Leitao et al., 2006), the current literature provides a coherent picture of what wildlife species may require in urban environments to survive. According to the research results, an ideal spatial pattern for wildlife habitat that ensures long-term presence, richness and abundance of wildlife species – and at the same time considers what humans require in the face of climate change-related issues such as urban heat island effects – can be summarised as follows:

(1) A combination of patches of different sizes from small to large, mostly connected through green and blue corridors, where possible, as well as a limited number of isolated patches of vegetation as urban wildlife refugia to avoid the spread of weeds and pests in event of unforeseen circumstances. If spatial connectivity is not possible, proximity between patches of vegetation should be increased through the incorporation of stepping stones;

(2) A heterogeneous network of different land cover type classes, including patches of indigenous and exotic vegetation for providing diverse habitats and food sources year-round for different species in the face of different circumstances;

(3) Topographically diverse patches of vegetation to provide diverse micro-climatic conditions in the face of impacts imposed by rapid urbanisation and climate change;

(4) A combination of compact and elongated patches of vegetation to meet the needs of wildlife species and people. Compact patches provide wildlife species with suitable habitats. While elongated patches play an important role in mitigating the ill effects of urban heat islands, both types of patches can supplement each other. For example, elongated patches of vegetation can be used by wildlife species as stepping-stones or additional sources of food. Likewise, compact patches can simultaneously contribute to a higher rate of evapotranspiration in order to help people and cities adapt to urban heat island effects (cf. Table 2).

Although globally accepted, the above-mentioned spatially-explicit patterns should not be considered as a panacea to address biodiversity issues in cities. In addition, they should not be used haphazardly. Instead, planning for biodiversity in cities must take *local realities on the ground* into particular consideration when using these patterns in order to maximise the odds of success. A considerate site- and species-specific attitude is therefore needed to use the spatially-explicit patterns.

Table 2: The role of landscape pattern composition and configuration in support of biodiversity in urban environments and spatially-explicit recommendations for landscape architecture

Components	**Urban biodiversity targets (**spatial requirements of wildlife species)	**Spatially-explicit recommendations for landscape architecture**
Indigenousness	• Indigenous plant species as an essential for ecological integrity; • Patches of exotic vegetation as supplementary habitats, foraging sources, stepping stones, and buffer zones.	• Increase the percentage of indigenous land cover type classes on an urban scale through re-vegetation, landscape restoration practices, and natural regeneration processes specifically in abandoned sites, ecologically damaged patches of vegetation, and brownfields; • Encourage people to plant indigenous species in their properties including private gardens and house backyards; • Utilise exotic species for the benefit of fauna, if they are not invasive or ecologically detrimental.
Land cover heterogeneity	• Diversity of land cover type classes as an index of habitat diversity and thereby urban biodiversity over time.	• Increase the number of land cover type classes on an urban scale though re-vegetation, landscape restoration practices, and natural regeneration processes; • Increase plant diversity on a micro-scale, wherever possible including along walkways, around golf courses, in playgrounds, and within cemeteries.
Land surface perviousness	• High land surface perviousness as an index of urban wildlife diversity and abundance, more specifically birds, reptiles, and invertebrates.	• Minimise paved areas in urban parklands, gardens, zoos, and other public green spaces; • De-pave coastal zones and increase green space coverage in urban parking lots; • Follow a more compact urban development to minimise imperviousness on a landscape level.
Patch size	• Larger patches of vegetation as a pool for a greater number of wildlife species over time.	• Protect large patches of vegetation from urban development and at the same time, preserve small patches of vegetation where required to provide stepping-stones or supplementary food sources between large patches to facilitate species movement.
Connectivity and proximity	• Connected patches of vegetation as corridors for species movement; • Isolated patches of vegetation as a barrier in the face of pest and weed dispersal (i.e. predator fauna and exotic flora), as well as climatic events).	• Plan and design green and blue corridors to connect patches of vegetation together and facilitate species movement between habitats and at the same time, allocate a number of isolated patches of vegetation to provide weed- and pest-free urban wildlife habitats in event of unforeseen circumstances.
Edge density/contrast	• Low edge density as a strategy for reducing edge effects; • High edge contrast as a barrier in front of disease spread, pest and weed dispersal, and wildfire; • Low edge contrast as a strategy for facilitating species movement.	• Use more compact forms when designing patches of vegetation to minimise edge density; • Minimise edge contrast through allocating similar land cover and land use activities where species movement between patches of vegetation is ecologically critical; • Maximise edge contrast through allocating dissimilar land cover and land use activities where there is a risk of disease, pest, and weed spread from one patch to another.
Landform diversity	• Topographical diversity as a great potential for species colonisation and concentration in the event of unforeseen climate change impacts such as intensified winds, sea level rise, and cold/heat waves.	• Avoid the modification of landform and reserve strategically important aspects of slopes as wildlife habitats and protect them from future urban development.
Shape complexity	• Compact patches of vegetation as a medium of reducing edge effects and at the same time, increasing patch core area.	• Use more compact forms to design new patches of vegetation. • Reconfigure the shape of patches of vegetation through plantation projects, landscape restoration practices, and natural regeneration processes, where possible.

5. Conclusion

Biodiversity loss in urban environments has already been initiated as a result of anthropogenic development; climate change is also estimated to accelerate this process. There is worldwide evidence to verify that biodiversity in urban environments, like elsewhere, depends profoundly on landscape pattern composition and configuration. If managed appropriately, the eight most important components of landscape pattern constructing spatial characteristics of urban wildlife habitats can play a key role in the presence, richness, and abundance of biodiversity in the long run despite the presence of anthropogenic development and climate change.

In-depth understanding of the role of the most important components of landscape pattern in support of wildlife species will inform the landscape architecture discipline in a way that supports biodiversity in cities, where conventionally there is not enough land, funding, and/or water to be dedicated to urban green spaces. In such situations, it is the composition and configuration of landscape patterns that contribute to urban biodiversity, not necessarily conventional development of green spaces or increasing the percentage of green space per capita.

Spatial ecology of wildlife species in urban environments is therefore essential knowledge to be developed and incorporated into the landscape architecture discipline, more than ever before, in order for urban policy makers to provide a robust basis for making informed decisions on land-use allocation and land cover conversion. This will be an initial step to help cities move from the notion of *urban development vs. habitat preservation* to *urban development with habitat conservation*.

Further research is required to address the current gaps in this field of landscape architecture research. The main research priorities include, but are not limited to, the following topics:

(1) Given that the components of landscape pattern are not equally important to wildlife species, both global and local survey studies are required to rank the most important components of landscape pattern based upon empirical experiences gained through long-term research and practice by subject-matter experts from different parts of the world in order to provide a picture of individual importance of each component of landscape pattern in relation to others. In addition to this, such studies need to address areas of conflict between what wildlife species and humans require in terms of spatial patterning of patches of vegetation in urban environments.

(2) Cities that have been established at ecosystem junctions (Alvey, 2006) should be identified and selected as research sites to undertake spatial analysis of landscape pattern composition and configuration in relation to the existing ecological processes in order to examine if current landscape patterns have the potentials to safeguard urban wildlife species against the local impacts of climate change and rapid urbanisation. Such research requires a reliable dataset of local information including climatic and environmental data as well as empirical information about the spatial ecology of keystone species present in the selected cities in order for landscape analysts to interpret landscape patterns in relation to the species' behaviours in space and time. The outputs are likely to reveal opportunities for the landscape architecture discipline to answer the question of what an optimised landscape pattern is to support wildlife species in the face of climate change impacts in urban environments.

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