Chapter 7
Urban Green and Biodiversity

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Abstract The chapter explores the relationship between urban green and biodiversity. Cities are home to a large number of native plant and animal species. Non-native species are an essential component for the species richness in the cities worldwide. The population of animal and plant species is not stable and the number of native species has been declining over the last decades and the portion of non-native species is increasing. Public and private gardening are main causes for the introduction of non-native species. The different contrasting attitudes towards non-native species between urban dwellers and nature conservationists are discussed. Three approaches are described representing different scales, namely the city in the region, the urban matrix and green patches. These three approaches offer a sophisticated view about the relationship between urban green and biodiversity and provide ways for a tailored management to improve biodiversity in urban areas. For each scale, recommendations for the management of urban green are presented. The chapter ends with basic principles for the development and management of green areas and green structures to enhance urban biodiversity and ecosystem services in cities.

Keywords Urban biodiversity · Native species · Non-native species · Species pool · Urban matrix · Patches

7.1 Introduction

The relationship between biodiversity and cities is ambiguous, or expressed in another way, cities are both the beast and the beauty with respect to biodiversity.

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The beast: urban development destroys and fragments natural habitats, increases the abundance and distribution of alien and invasive species and strains the local, regional and global ecosphere. Urban development is responsible for one of the most serious global issues, that of biotic homogenization. The beauty: in relation to their surrounding landscapes, cities stand out because of their richness of species, a wide range of habitats and efficient use of land for human settlements. Cities have become the main habitat for several plant and animal species and a refuge for some rare species, as well as providing opportunities for most of the world's human population to integrate experiences of nature into everyday life (Müller et al. 2010; Elmqvist et al. 2013).

The Convention on Biological Diversity defines 'urban biodiversity' as: 'The variety and richness of living organisms (including genetic variation) and habitat diversity found in and on the edge of human settlements. This biodiversity ranges from the rural fringe to the urban core' (SCBD 2012).

On the one hand, it is reasonable to assert that the past, present and probably future total biodiversity of any city in the world is not known and never will be. On the other hand, the problem is that the complexity of determinants and the spatial and temporal dynamic of cities (Andersson 2006) preclude simple starting points and lines of argument to explain causal linkages between biological diversity and cities (Kinzig et al. 2005). Despite these difficulties the chapter examines some aspects of the relationship between urban green and biodiversity although it is appreciated that in doing so only partial explanations are possible at the present time.

However, in terms of a general principle, there is a simple message: more green = more biodiversity (Aronson et al. 2014; Beninde et al. 2015; Turrini and Knop 2015). Green areas such as parks other green elements and even a single tree provide the basic units that allow plants and animals to survive in urban areas.

To better understand the underlying processes, it is helpful to use three overlapping approaches, representing different eco-geographical scales. These approaches have been chosen to present the current knowledge about the relationship between the green components of cities and biodiversity as well as opportunities to increase both aspects of biodiversity by the management of green areas and other elements. The three approaches are:

1. City in the context of the region, because cities are embedded in biogeographic regions and are connected to the surrounding landscapes.
2. Urban fabric of the city as a whole, which focuses on the intimate mix of built-up and non-built-up areas and structures.
3. The local or site level, which looks more closely at green spaces or patches – green islands in the ocean of the concrete city.

After this introduction the chapter is divided into four sections starting with some general remarks about the origin and composition of the urban flora and fauna and followed by an examination of some aspects of non-native species. Then we present the above mentioned three approaches in the context of the development of biodiversity of cities. The final section contains the conclusion. Some key concepts and terms are defined and explained in Box 7.1.

Box 7.1

Definitions

Urban Biodiversity
The variety and richness of living organisms (including genetic variation) and habitat diversity found in and on the edge of human settlements. This biodiversity ranges from the rural fringe to the urban core (SCBD 2012).

Green Components
Green area is defined as land that consists predominantly of unsealed, permeable, 'soft' surfaces such as soil, grass, shrubs and trees. It includes all public and private areas of parks, gardens, play areas, wasteland, green roofs and so on as well as other green spaces with other origins like natural areas, agricultural land, orchards, nurseries. The term '(urban) green area' is used here as a short hand term and includes all these categories. Trees, hedgerows and other green single structures which support organisms in cities are described here as *green elements*.

Both green areas and green elements are summarized under the term green components.

Native Species
Native or indigenous species have originated in a given area with or without human involvement or have arrived without intentional or unintentional intervention of humans from an area in which they are native (Scholz 2007). In a strict sense, only such taxa can be defined as native if their genomes are part of the original regional species pool.

Non-native Species
Alien, non-native, non-indigenous, foreign, exotic means a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans), and includes any part, gametes or propagule of such species that might survive and subsequently reproduce (IUCN 2000).

7.2 Origin, Composition and Development of Plant and Animal Species in Urban Areas

It is often stated that the physical and chemical environment of cities, for example climate, water regime, soil structure, air, water and soil quality and vegetation cover are completely different from that of the surrounding landscape and that these altered conditions have a significant influence on the composition of the plant and animal populations (Sukopp and Wittig 1998; Douglas and James 2015) creating novel ecosystems (Kowarik 2011) of which green areas and structures are components.

Urban areas are very recent in the context of biogeographical history of the fauna, flora and other organisms on earth (Lenzin et al. 2004; Kelcey 2015). They are also highly dynamic because of continual changes that occur as the result of spatial expansion and changes in land use. Growing and shrinking, development and redevelopment of sites, technological innovations and changes in human and political priorities that influence values and therefore the planning, design and management of built-up and green areas. As a consequence the flora and fauna of cities lack stability (Sattler et al. 2010), including those that occur in public and private green areas. Only a subset of native species can cope with environmental changes, which occur with urbanization (Kark et al. 2007a; Williams et al. 2009).

Nevertheless many species representing various taxonomic groups such as vascular plants, birds and butterflies can be found in city areas (Table 7.1). However, this chapter concentrates mainly on terrestrial green issues in relation to vascular plant species and birds because most of the current knowledge is based on them. The total administrative area of a city includes parts of the surrounding landscape and various parks and green areas. As a result of their structural and habitat diversity, cities can accommodate a high level of species richness in terms of plants, animals and other organisms. It is essential to state the geographical context on which species-richness is measured, namely the total administrative area (the current baseline) or the area within the limits of development. With respect to both the total city area and vascular plants, cities like Berlin, Washington DC and Seoul are hotspots of biodiversity. At the more detailed level, closer to the city centre the environment becomes more inhospitable, green areas smaller and plants and animals more scarce (McKinney 2006a).

Although only relatively few species can survive in inner urban areas, some of them occur in high abundances. Many of these common species have migrated from their original natural habitats (especially rocks and cliffs) to urban centres. For example, in European cities the dominant breeding bird species include Rock Dove (*Columba livia domestica*), Collared Dove (*Streptopelia decaocto*), House Sparrow (*Passer domesticus*), Blackbird (*Turdus merula*), Starling (*Sturnus vulgaris*) and Black Redstart (*Phoenicurus ochruros*). Other species also breed in urban areas but feed (at least partially) outside it, for example Common Swift (*Apus apus*), Kestrel (*Falco tinnunculus*) and Eurasian Jackdaw (*Corvus monedula*) (Kelcey and Rheinwald 2005).

Table 7.1 Some basic data and species numbers of selected cities round the world

City	Country	Population	Population/km^2	City area in km^2	Developed area in km^2	Green space in km^2	Annual average temperature	Number of vascular plant species	Number of bird species	Number of Lepitoptera species
Adelaide	AU	1,203,873	659	1,826.90	n.a.	14.50	16.40	1,664	291	n.a.
Auckland	NZ	1,461,900	299	4,894.00	n.a.	n.a.	15.30	542	103	15[a]
Berlin	DE	3,510,032	3,927	891.70	70.29	22.50	8.90	1,393	148	n.a.
Curitiba	BR	1,851,215	4,056	434.97	n.a.	5.06	17.83	1,766	366	468
Edmonton	CA	817,498	1,168	699.80	29.73	n.a.	3.90	487	178	68
Hamburg	DE	1,802,041	2,349	755.30	44.40	23.30	9.00	1,086	160	n.a.
Montreal	CA	1,649,519	4,538	363.52	n.a.	5.44	6.00	1,063	124	274
Moskau	RU	11,503,501	4,583	2,510.00	n.a.	n.a.	5.00	1,647	152	n.a.
Nagoya	JP	2,267,048	6,945	326.43	56.53	10.28	16.10	1,000	231	75
New York	US	8,175,133	10,356	789.40	65.40	19.70	12.40	2,177	n.a.	87
Nitra	SK	78,875	785	100.48	n.a.	n.a.	8.40	608	144	n.a.
Seoul	KR	9,794,304	16,175	605.52	57.53	31.92	11.80	1,794	205	n.a.
Singapore	SG	5,183,700	7,257	714.30	n.a.	13.00	27.30	2,145	376	295
Toulouse	FR	440,204	3,721	118.30	n.a.	n.a.	12.60	767	92	n.a.
Zurich	CH	390,082	4,245	91.90	54.33	37.19	7.90	1,353	97	n.a.

[a]including migrants n.a. = not available

Sources Own data by P. Werner collected from local publications and websites, City Biodiversity Index fact sheets presented on COP 11 in Hyderabad 2012, Aronson et al. (2014)

The predominant urban birds are common species with a wide geographical range, being represented in temperate and Mediterranean cities by omnivores and granivores (Clergeau et al. 1998; Chace and Walsh 2006; Kark et al. 2007b) and by frugivoros and granivoros in tropical cities (Lim and Sodhi 2004).

Typical urban plants in Europe include those found in the following natural habitats (the English names follow Stace 2010):

- river banks, floodplains, woodlands and swamps: Ground Elder (*Aegopodium podagraria*), Hedge Bindweed (*Calystegia sepium*), Cleavers (*Galium aparine*);
- periodically flooded, nutrient-rich mud, sand and gravel surfaces of inland waters: Trifid Bur-marigold (*Bidens tripartita*), Creeping Cinquefoil (*Potentilla reptans*),
- strand lines, dunes and coastal rocks: Common Couch (*Elymus repens*), Perennial Sowthistle (*Sonchus arvensis*),
- areas of wind throw, clearings: Creeping Thistle (*Cirsium arvense*), Spear Thistle (*Cirsium vulgare*),
- open, disturbed ground, most of which has originated as the result of human activities, for example Annual Meadow Grass (*Poa annua*), Shepherd's Purse (*Capsella bursa-pastoris*) and Common Nettle (*Urtica dioica*).

The predominant characteristics of these urban plants are: the absence of hygromorphic leaves, increased leaf area index, wind-pollinated flowers, reproduction by seeds, short life-span or perennial hemicryptophytes.

When considering the habitats and species composition of the administrative area of a city, Kowarik (2005) identified four basic categories of nature (Table 7.2).

It is the variety of natural categories that is one of the reasons for the richness of species in urban areas compared to the lower number of species found in intensively managed arable land and forests.

A further reason for the species richness in relation to vascular plants is the presence of a large number of non-native species that have been introduced by human activities; they comprise 30–35% of the total number recorded in a European city. A similar situation applies throughout the world with exceptions of New Zealand and Australia. The same picture is true for birds but on a much lower level, only 10–15% of bird species in cities are non-native (Aronson et al. 2014).

In addition, many cities contain more native species than the surrounding landscape and, more surprisingly, a larger proportion of the regional species pool (La Sorte et al. 2014). An underlying cause of the species richness is that many

Table 7.2 Four basic forms of nature found in cities (from Kowarik 2005)

Nature 1	Old wilderness	Remnants of pristine nature
Nature 2	Traditional cultural landscape	Continuity of former agricultural or forested land
Nature 3	Functional greening	Urban parks, green areas and gardens
Nature 4	Urban wilderness	New elements by natural colonization processes particularly distinct on urban wastelands

cities, especially in Central Europe, have been established in productive and diverse landscapes combined with relatively stable environment conditions. This indicates that cities are often located in landscape settings that are naturally species-rich (Kühn et al. 2004). As a consequence, there is a special responsibility on central and local governments and others to protect this richness and to develop and manage green areas accordingly.

However, a comparison of the plant inventories of several cities on various continents has found a loss of native species ranging between 3% and 46% over a period of 100 to more than 150 years. The mean loss found in Europe is about 10–12% (Jackowiak 1998; Bertin 2002), for example a reduction of both native species and archaeophytes, but an increase of neophytes is reported in Frankfurt, Halle/Saale and Zurich. In Zurich the number of neophytes was higher than the number of native vascular plants that are thought to no longer occur in the city. The opposite has occurred in Frankfurt and Halle where the decrease of native species was larger than the increase of new species (Landolt 2000; Stolle and Klotz 2005; Gregor et al. 2012). It is instructive to compare those situations with the findings of Tait et al. (2005) and McKinney (2006b) who report the proportion and in many cases the absolute number of non-native species is still increasing

Successful ‘urban exploiters’ and ‘urban adapters’, which can be non-native or native species, are usually found in a large number of mapped grid fields or habitats of a city. However, during recent decades, the general trend appears to be that the proportion of species found in a larger number of grids, is declining. Conversely the proportion of species, including still common species, occurring in only a few sites is rising continually, which suggests a growing potential of threat (Chocholouskova and Pysek 2003).

7.3 Non-native Species

There is a voluminous literature on non-native species (many published the last few years), which it is impractical to review in this chapter, which focuses on some of the more important issues. Alien, non-native, non-indigenous, foreign, exotic means a species, or taxon of lower rank that occurs outside its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans), and includes any part, gametes or propagule of such species that might survive and subsequently reproduce (IUCN 2000).

As described earlier, cities are important centres for the importation, establishment and distribution of non-native species. So far as plants are concerned, deliberate introductions for horticulture, forestry and landscaping purposes play the major role while unintentional introductions in goods are of less importance (Müller et al. 2010).

It is apparent that early hominids started to select and cultivate plants from many localities for food, medication, dyes and the production of spices from different localities. Consequently, it is likely that the deliberate introduction of species into cities was contemporaneous with the building of the first cities in the Middle East. It is probable that even in these times there was at least some appreciation of the aesthetic qualities of plants, which was certainly the case by the time of the ancient Greeks. The Romans introduced fruit trees into the cities they conquered or built whilst monks created physic gardens for the production of medicines (many are now known as liquors). The building of castles and large houses with extensive grounds gave rise to plant hunters who scoured the world for 'new' species and varieties to satisfy the requirements of and competition between the aristocratic owners. These activities ultimately gave rise to the horticultural trade and plant breeding.

By the 19th century, interests in gardening were being pursued by the 'middle' classes, whilst wealthy industrialists were creating public parks. These interests resulted in the expansion of the horticultural trade to propagate plants in much greater numbers and produce more varieties by selection and/or breeding. Since the 1960s, gardening (including allotments and house plants) has become a very popular and fashionable recreational activity of ordinary people whilst the more affluent hire garden designers and contractors to create and maintain more exotic, complex gardens to compete with their peers. During the same period, local planning authorities have required and continue to require residential, retail, commercial and industrial developments to be accompanied by landscape schemes although the quality varies considerable. Other key drivers for the introduction of non-native plant and animal species include the management of public parks, land restoration, creation of sports fields, lawns and other areas of grassland using imported grass seeds of unknown origin.

As a consequence, the 'nursery and horticultural trade' has developed into a large commercial business operating from a relatively small number of countries producing (often by cloning) more and more plants of a limited pool of taxa for export. In addition, plant breeders are in 'hot pursuit' of new products (i.e. plant varieties) for their own commercial purposes and to satisfy the insatiable demands of the horticultural, landscape and agricultural industries. The result is thousands and an ever increasing number of varieties of trees, shrubs, 'flowers,' soft and hard fruits, vegetables and cereals, most of which are for planting in urban areas. The only change is the replacement of old varieties with new according to fashion. Foresters, horticulturalists, landscape architects, etc. have a theoretical view of what a good plant, of a specific taxon should look like. Producers of plants select for these preferred phenotypes and reject phenotypes that do not conform to the model. This selection is having a very serious detrimental effect on genetic diversity by reducing the amount of variations in genotypes.

It is estimated that since the Neolithic period, 12,000 species have been introduced into Central Europe for ornamental and cultural purposes, and approximately 10%, i.e. 1100 of those plants have become naturalized (Lohmeyer and Sukopp 2002). Stace and Crawley (2015) report that most non-native species have short 'life expectancies' in a particular locality. Consequently, there is likely to be a high turnover of non-native species in terms of losses and gains, replacement and changes in abundance and distribution.

The introduction of non-native species includes taxa that might become invasive. Cities are sources of non-native species and therefore of invasive species which colonize the surrounding landscape where they may out-compete native species, changing natural vegetation stands, causing loss of crop yield or damaging dams for flood control and much more. An invasive species is a species that has been introduced to an environment where it is non-native and whose introduction causes environmental or economic damage or harm to human health (IUCN 2015). However, only a small number of non-native species have become invasive and cause problems. For example, in Germany 115 non-native plants are rare, 559 occur occasionally and 609 have become naturalized, and of the latter about 30 are classified as invasive. In terms of non-native animals, it is estimated that nearly 5% of those that have established have the potential to become invasive (BfN 2016). In cities, invasive species are not a problem because the ecological situation prevents them from having an impact on the biological diversity.

There is a growing tension between the attitudes and values of some of the biological disciplines and nature conservationists and between them and people as a whole in respect of non-native species. Many urban dwellers like non-native plants species because they have attractive forms, foliage, flowers or fruits, useful for hedging and providing screens and are sometimes of wildlife value (e.g. Butterfly-bush *Buddleja davidii*). On the other hand most conservationists consider them detrimental to wildlife and wish to remove exotics or prevent them from being planted, even in cities. There are many conflicting, strongly held and often highly emotional opinions, the following are examples from Britain. Some nature conservationists are strongly opposed to the planting of non-native tree species, especially Sycamore (*Acer pseudoplatanus*), because they support fewer species of Arthropod compared with native species, especially Pedunculate Oak (*Quercus robur*). Others take the contrary view and argue that a large number of individuals of a few species is important (as is generally the case with the non-native species). In his book on urban ecology, Gilbert (1989) makes a special plea for the value of the alien species, Japanese Knotweed (*Fallopia japonica*), in providing cover for some woodland species in Britain. Especially for novel ecosystems, it is noted that non-native species can shelter the regrowth of native species and enhance ecosystem services from impacted or designed states (Morse et al. 2014). There is also a clash of cultures—science and aesthetics; for example, ecologists wish to remove *Rhododendron ponticum* because it suppresses the native flora whilst the public at large object because it is very attractive during the flowering season. Florists like some the Fleabanes (*Conyza* spp.) very much for flower arrangements whereas ecologist would like to see them exterminated.

In a strict although correct sense, a species is classified to be native when considered in the context of the whole country, but it may be non-native in a particular region(s) if it does not occur naturally in that region (Box 7.1). It is also essential to consider variation in the genotypes of the regional genetic pools—because of the structure and operations of the international horticultural and forestry trades native taxa used in landscape schemes, parks and gardens generally have non-native genomes. In Britain, at least, since the 1970s it has been fashionable (possibly an obsession) to create 'wildflower meadows' in some parks, road verges and land awaiting development or unused land. The proposals have three objectives, aesthetic and increasing floristic, and faunal diversity habitats for invertebrates. Although the objectives have been achieved to varying degrees, they have two negative aspects in terms of biodiversity. First, some of the species did not occur in the region or in the country. Second, at least in the early years, the seeds originated from outside Britain, often from agricultural strains from elsewhere in Europe, resulting in native British taxa with non-native genomes. Native species versus non-native genomes is often overlooked in landscape planting as a whole. Therefore, to save and enhance the gene pools of regional species, some institutions (for example, in Germany several federal states and local authorities) have decided to plant only regional genotypes of woody plants or use regional seed banks for meadows on public green areas. As mentioned above, sensu stricto, a taxon that is moved by human activity from a part of a region where it occurs naturally to a region in which it does not occur naturally is an alien taxon in that region just as much as if it was imported from another country. That approach raises two major matters to which scientists do not have the answers. First, detailed knowledge of the extent of variation in the genome of a taxon and its significance in evolutionary, pathological and other terms. Second, the taxonomy of an organism can vary across countries and continents.

7.4 Three Scales—Three Approaches

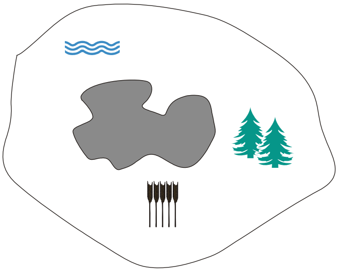
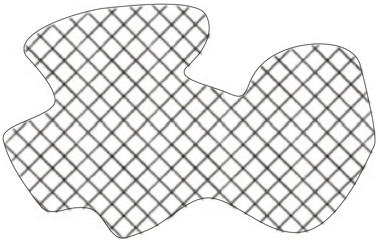
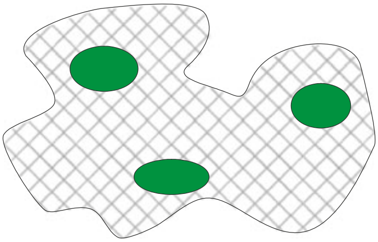
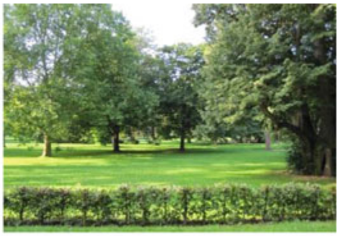
To analyze and understand the biodiversity that can be found in a city and to develop local guidelines for interventions to maintain and improve urban biodiversity in the green components, it is helpful to use three approaches representing different scales (Table 7.3).

7.4.1 City in the Region

Virtually all cities originated from small settlements mainly on trade routes, relatively few were developed de novo on 'green field' sites; those that were include Abuja, Brasilia, Canberra, Lelystad, Milton Keynes and St. Petersburg. The biodiversity of these cities before, during and 'after' the development has not been monitored and measured in qualitative or quantitative terms.

The plants and animals of urban areas are part of the regional species pools, which interact with the local pool. In relation to birds, the surrounding landscape is the dominant source and the urban habitats are sinks of many but not of all bird species (Schwarz and Flade 2000). Consequently, changes in the regional species

Table 7.3 Three scales of approaches to analyze urban biodiversity

Scale		
City in the region		
Urban matrix		
Green patches		

pool will have an impact on the development of the bird populations in the city. Therefore, a reduction of the species diversity in the surrounding area of a city may cause significant changes in the plant and animal populations regardless of whether the habitat quality of green spaces in the city are suitable or not (Tait et al. 2005).

From a global perspective it is essential to appreciate that cities are embedded in different biogeographical regions and landscape settings, including cultural landscapes and wild lands. Consequently, there are many inter-relationships between cities and their surroundings. Urban areas encounter many different existing natural conditions and landscapes of the different biomes that have been more or less modified substantially by human activities (Palmer et al. 2008), for example biospheres of boreal forests and deserts.

Boreal forests are characterised by coniferous trees that cast a dense shade on the forest floor, relatively short of soil nutrients, moderate temperatures in the summer and a long harsh winter. As a result, only a few stress-tolerant species occur in them. It follows that the habitat characteristics of the boreal forests are in marked contrast to those in cities, especially during the winter months. Cities such as Oslo and Vancouver are remarkably warmer than surrounding environs and the growing season is noticeably longer. Urban green spaces are mostly open and productive landscapes influenced by human recreation activities and continuous management. Because of the distinct seasonality of summer and winter in the high latitudes, urban areas have a special function in winter, for example serving as a shelter for many species (Clergeau et al. 1998; Murgui 2009). Thus in cities, species whose natural distribution lie further south can selectively move the boundary further north (Luniak 2004; Kowarik and Säumel 2007).

The hot and dry deserts located in several parts of the world differ widely in their floristic composition, but their basic characteristics are similar: sparse vegetation cover, extremes of temperature, low soil fertility and scarcity of water. As a consequence, the regional flora and fauna is dominated by specialists adapted to these harsh conditions. The vegetation consists of dwarf trees and shrubs whilst many of the native animal species are nocturnal and confined to small habitats. The variation between dry and humid years exercises a major influence on the vegetation (Buyantuyev et al. 2010). Cities built in these extreme conditions such as Dubai and Phoenix are not as dry as the surrounding natural areas. They are more humid and have generally higher soil-water content because of numerous artificial water bodies and the irrigation of parks, gardens and even streets (Pickett and Cadenasso 2009). Irrigation partly compensates for differences in the water regime between drier and wetter seasons or years and with increasing green areas and ‘woody’ elements, generalist diurnal animal species occur in a sufficient amount and variety of habitats.

As some Australian cities demonstrate, additional factors such as the length of time following the cultural reshaping of the original (pristine) landscape and the time lapse since urban development processes also play an important role (Tait et al. 2005). The time period (duration of co-evolution) in which the regional pool of species is formed under the influence of silvi- and agricultural as well as urban development determines the relationships of the regional versus the urban pool of species. Over the course of the last 8000 years and more, man-made landscapes have been created throughout Europe, initially in the Mediterranean region. Both the rural and the urban landscapes are based on long adaptation processes to anthropogenic influence. Considerable similarity exists between the Mediterranean landscape and green structures in cities not only because both consist of open, sparsely forested land but also because the land was (and in part still is) compartmentalized. Rome is a good example of this; compared to cities of Central Europe it exhibits a relatively high percentage of native vascular plants of the region (Celesti-Grapow et al. 2006).

In the Central European environment, urban growth tends to take place primarily on agricultural land. While this also occurs in areas with rapid suburbanization (such as in the United States) or rapidly growing mega-cities, these scenarios are also likely to have a direct impact on areas of semi-natural wilderness (Grove et al.

2006). The development of urban areas directly in wilderness areas results in very different interactions between local and regional species pools, because there is a severe ecological break between urban and wilderness areas.

The urban fringe is the transition zone between the urban and surrounding areas. The designing of that zone has an impact on how species can enter or leave the urban areas. The zone, especially in relation to plants, form an important ecotone that supports a high level of species richness and diversity. These 'edge of town' areas are often used for the development of business parks and retail outlets, which can be of value for biodiversity strategies (Snep 2009).

Some studies have simulated the impact on local biodiversity by two varying scenarios of urban growth; first, a more compact growth resulting in large green areas and densely built houses with small gardens; second, urban sprawl comprising detached houses with large gardens. The simulations found that the compact growth has a smaller impact on the local species diversity than urban sprawl (Sushinsky et al. 2013; Varet et al. 2014).

The following recommendations for planning and management of green components of cities emerge from the analysis in this section:

- the regional species pool is the base for the local species pool and must be considered at all stages;
- the increase in species diversity of the surrounding areas has a positive impact on the local areas;
- improving and creating opportunities for the movement of species from the surrounding landscape to and from the urban areas. Such connections and transition zones are needed for both 'generalists' and 'specialists' plant and animal species;
- the spread of invasive species from urban areas into the surrounding semi-natural or natural areas should be prevented by management activities;
- compact growth including larger areas of green is preferable to urban sprawl.

7.4.2 Urban Matrix

A review of the literature shows that urban biodiversity is mainly assessed on floristic and faunistic studies conducted in parks and public green areas. The built-up areas (the urban fabric) were once described as unlivable habitats and therefore not recognized in biodiversity research (Franklin and Lindenmayer 2009). For the purpose of this chapter, built-up areas referred to as the 'urban matrix' are defined as a mix of densely and less densely built-up areas, comprising a relatively small-scale mosaic of buildings, streets, open and green spaces.

Only in the last few years has the biodiversity of the 'urban matrix' been studied and analyzed more intensively. These studies have demonstrated and confirmed studies made in previous decades that without the consideration of the urban matrix the knowledge of the biodiversity in a city would be incomplete (Lizee et al. 2011;

Conole and Kirkpatrick 2011). The influence of the vegetation of the whole city, including the urban matrix, is the key to increasing the species-richness and diversity in urban areas (Jones and Leather 2012; Pellisier et al. 2012).

The following are examples to illustrate the function of the urban matrix. Using presence-absence data for 16 bird species in the rural-urban interface, Taylor et al. (2015) demonstrated that the models fitted successfully when consideration was given to both patch and matrix characteristics. In this study the important matrix characteristic was the degree of tree cover. Several studies of the Barred Owl (*Strix varia*) found that suburban neighbourhoods with a well-developed stock of trees are similar to patches of forests (Dykstra et al. 2012). A study of the Red Squirrel (*Sciurus vulgaris*) showed that explanatory models of its occurrence in patches are significantly better if the permeability of the matrix is taken into account in the analysis (Verbeylen et al. 2003). Lizee et al. (2011) found that the configuration of the matrix had a significant influence on diversity of urban butterflies. It was concluded both matrix configuration and distance from the regional species pool overrides park size in contributing to variations in species richness. The amount of surrounding habitat areas and structures which correspond with the habitat functions of park and green spaces can minimize the substantial breaks between green patches and surrounding matrix. For that reason, the 'effective' size of parks may be larger than their actual size (Loeb et al. 2009).

There is an underestimation of the amount of small green areas inside the urban matrix. One reason is simply the fact that the matrix comprises mainly private property that cannot be accessed and studied as easily as public open space (Hodgson et al. 2007). In many cities these private green areas exceed the total amount of public green areas. For example, the developed city area of Hanau, Germany, contains 400 ha public parks and green spaces but the total amount of private gardens and private green areas, e.g. located between block of flats total nearly 800 ha (Werner 1999). If the green areas between blocks of flats were designed and managed to create a complex vegetation structure, they would provide valuable habitats for many more animal species.

It is estimated that in the United Kingdom, for example, between 19 and 27% of the area of cities is taken up by domestic gardens (Smith et al. 2006), providing high-quality habitats for plants and animals. As demonstrated by a study on Wood Mice (*Apodemus sylvaticus*), domestic gardens may further reduce the deleterious effects of fragmentation (Baker et al. 2003).

Meta-analysis and simulation models of fragmented terrestrial landscapes (such as urban landscapes) demonstrate the major influences of the matrix that surrounds green patches (Prugh et al. 2008) whilst lower matrix quality increased the requirements for the improvement of the habitat quality of the patches (Dunford and Freemark 2005). Taylor et al. (2015) came to the conclusion that the supporting function of the matrix increases with decreasing patch size and therefore the matrix can make a significant contribution to the importance of biodiversity in urban areas.

The analysis in this section gives rise to the following recommendations for planning and management of green components:

- improving the permeability of the urban matrix by increasing the vegetation cover and diversity by the creation of green areas, for example pocket parks, green roofs, green 'corridors' along streets, riversides and other green elements such as trees and green facades;
- increasing the vegetation cover around parks to enhance the interactions between the green and surrounding areas;
- combining the design and management of public and private areas to improve species mobility and interactions between public green areas and the surrounding private green components.

7.4.3 Green Urban Patches

The importance of urban parks and green spaces is clearly illustrated by a study in Flanders, Belgium. The investigated urban and suburban parks of Flanders comprise only 0.03% of the total area but contain about 29% of all wild plants and over 48% of all breeding birds in the region (Cornelis and Hermy 2004). Some 53% of bat species occurring in France that use green and forest areas can be found in urban parks (DeCornulier and Clergeau 2001). These few examples are sufficient to demonstrate that urban parks and green spaces are the backbones of species richness and diversity in urban areas.

Many scientists state that the habitat quality of green urban areas is determined by structural features (for example horizontal and vertical complexity and the diversity of microhabitats), size, age and the relationship with other habitats (Stenhouse 2004). The size and age of green spaces are related to the increase of structural diversity and diversity of microhabitats. To increase the species richness of birds and other animals, it is necessary to provide important features such as an open tree canopy with a cover of not less 30%, an age range of tress, including some with cavities, a shrub layer and a field layer with small structures offering shelter for small mammals, and good protection from feral cats and dogs (Garden et al. 2010; Taylor et al. 2015; Yang et al. 2015). Nielsen et al. (2014) reviewed the empirical findings of research of species richness in urban parks across all taxonomic groups that have been studied. They conclude that diversity of habitats and microhabitat heterogeneity contained in urban parks appears as the most decisive factor for the overall species richness in urban areas.

In nature conservation, there is a long lasting debate about the relationship between large and small areas, the so called SLOSS discussion—single large or several small (Tjorve 2010). Meanwhile, it is clear that both large tracts and small fragments have conservation value and that is also true for urban areas (Taylor et al. 2015). Large areas provide important reservoirs of species because they are able to support viable population while fragmented small areas have the function of stepping stones. However, cities have limited space and therefore there is a lack of large green areas and the creation of such areas is virtually impossible. The exception occurs if redundant large industrial or military areas can be converted to open spaces providing that there is no pressure for development or politicians have decided to leave them as open space. For these reasons the approach has to be changed to focus on small patches. Studies demonstrate that each small green space can provide different benefits for different species that can enhance species diversity if it is used as an integrated concept (Rega et al. 2015). Beyond that, small green patches distributed throughout the urban area offer more opportunities for people to have easier contact with nature.

Many rare and endangered species are found in urban semi-natural remnant areas. These remaining spaces do not only exist in the urban fringe but also in the middle of mega-cities. Notable examples of pristine habitats wholly or partly embedded within a city include the Mata Atlantica Forest in Rio de Janeiro, the remnant tropical evergreen forest in Singapore, the National Park El Avila with its rock faces in Caracas, various remnants of bushland in Perth, Sydney and Brisbane, natural forests in York (Canada) and Portland (USA), and rock faces and outcrops in Edinburgh (Heywood 1996; Miller and Hobbs 2002; Edinburgh Biodiversity Partnership 2008).

These examples demonstrate a further important point. The ‘urban standard’ of public and private managed green areas is short-mown grass and well-maintained (neat and tidy) sites. However, green areas that are hotspots of biodiversity in cities often do not comply with the ‘urban standard’; they include (Figs. 7.1, 7.2, 7.3 and 7.4):

- pristine remnants of native vegetation (Antos et al. 2006);
- parks and gardens with unchanged use and management over decades or even centuries (Kowarik 1998; Celesti-Grapow et al. 2006);
- unmanaged areas with natural succession and the emergence of differentiated vegetation structures (Hansen et al. 2005);
- large green areas of open, cultivated or forest land.

In summary it can be noted for green spaces that:

- structural diversity of the vegetation is one of the most important factors;
- size of habitat provides the opportunity to increase habitat structures and the variety of micro-habitats;
- habitat size is often linked to an increase in the number of species but the positive correlation between species richness and area is a gross simplification due to underlying processes that have to be considered;
- large and connected green areas are extremely rare in cities and should be protected;
- small patches have a function that is often underestimated;
- habitat age has a variety of aspects that comprise

Fig. 7.1 Remnants of a pristine tropical rain forest in the central catchment nature reserve of Singapore

  - pristine remnants, unchanged use and maintenance over decades or even centuries and
  - succession and the emergence of differentiated vegetation structure;
- quality of habitat networks can be described as spatial and functional connectivity.

More specifically, the more structurally complex, the larger, the older and the less isolated a habitat area is, the better are the chances for a high level of biological diversity (Angold et al. 2006; Chace and Walsh 2006).

7.5 Conclusion

This chapter has examined the provision and management of green spaces and structures that provide opportunities to enhance biodiversity and some ecosystem services in cities.

Cities have been created by human endeavours throughout the world for several millennia, mainly as economic and political centres. On the one hand they represent the pinnacle of human achievement whilst on the other they contain the depths of

Fig. 7.2 Garden of the temple 'Komyo zen-ji' in Dazaifu, Fukuoka

human depravation. Cities were often founded in landscapes that are naturally species rich. The expansion of cities has and is likely to continue to incorporate elements of the adjacent rural landscape with natural habitats and species to generate an urban-wilderness interface. The consequence is that pristine or semi-natural habitats survive in scattered patches of various sizes within the city.

The result is that the cities and their surroundings comprise spatially separated patches of high biodiversity in a matrix of simplified habitats with low biodiversity. This has given rise to a form of commensalism whereby the two elements rely on each other for the interchange of species. The most appropriate way of determining what positive action is required to improve biodiversity in cities is to examine the quality and species composition of the habitats and their connectivity in the context of a three-level eco-geographical hierarchy—the city in the region, the urban matrix and the green patches. In conceptual terms, the three domains represent overlapping sub-sets in multi-dimensional space.

The fundamental solution is the creation of a 'double' wheel whereby the primary centre (the city) is connected to the outer rim by spokes of green connectivity with HUBS (High Urban Biodiversity Sites) occurring within the primary centre and connected to its margins by secondary green 'spokes. The quantitative and qualitative structure of the connectivity is critical to the interchange of species between the three components. Aerial species are probably the least constrained followed by aquatic species (watercourses, including canals, are the only

Fig. 7.3 Südgelände, a ruderal area in Berlin

continuous habitat that flows through the landscape). The most disadvantaged are terrestrial species that do not have the advantage of continuity.

The planning, design and management of cities has resulted in some positive and negative impacts on biodiversity. From the earliest times, it is likely that people introduced plants into cities for food or aesthetic reasons. That trend has continued through the millennia resulting in the continual deliberate introduction of more and more species and varieties from other localities throughout the world. The consequence is that 30–35% of the plant species now recorded in cities are non-native; it also seems likely that the quantum of plants of non-native taxa is significantly higher than native taxa (of all ranks) Nevertheless, it is also suggested that cities may contain more native species than their surroundings. The combination of these two factors means that cities generally have a higher plant diversity than their surroundings. A similar principle applies to birds, although the figures are lower.

With respect to the above-mentioned three levels, the development and management of green areas and green structures to enhance urban biodiversity and ecosystem services in cities can be condensed in the following principles:

On the regional or landscape scale

- Improving the habitat quality of the surrounding landscape
- Connecting the regional species pool with the local species pool by green networks and permeable transition zones.

Fig. 7.4 The Tempelhofer Feld, a former airport area, in Berlin

On the city scale

- Improving the green cover and structures of the urban matrix

On the patch or habitat scale

- Improving the habitat quality of the patches
- Connecting the patches.

The implementation of these principles does not only increase urban biodiversity and ecosystem services but it is a big step to a sustainable, resilient and human-friendly city, too.

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