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Co-existing with wildlife in cities:

a literature review on nature-inclusive urban development

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Co-existing With Wildlife in Cities:

A Literature Review on Nature-Inclusive Urban Development

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Abstract

With a rapid increase in urbanization across the globe, it is important to understand how this affects biodiversity, from a conservational point of view. The potential of urban environments for biodiversity is widely recognized and has caused an increasing interest on the part of (landscape) architects, planners and urban designers to construct more nature-inclusive urban developments to enhance biodiversity in cities. The report presents a pioneer study on the evidence and current state of the academic literature on nature-inclusive urban development. It addresses the main arguments to include nature in the urban development, discusses different spatial scenarios for implementation including building, plot, block, street and district level measures that can be used, and reflects upon the way forward in nature-inclusive urban development.

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Table of Contents

1. Introduction

Urban areas house the majority of the world's population. Nowadays, 55% of human populations live in cities, with percentages up to 68% expected to live in urban areas by 2050 (UN, 2018). With this high percentage of people living in urban areas, research in urban ecosystems has been increasing (Barot et al., 2019). Urban areas often differ from the environmental conditions present in surrounding areas, such as higher temperatures, food resources and predation risks. This ongoing urbanization does not only have environmental impacts, such as increasing energy use and greenhouse gas emissions, but it also affects the wildlife associated with urban areas.

With a rapid increase in urbanization across the globe, it is important to understand how this affects biodiversity, from a conservational point of view. On the one hand, urbanization can cause biodiversity loss (McKinney, 2008). This decline in biodiversity is caused by a decrease in habitat structure complexity (Savard et al., 2000) and the decrease in greenery areas, which normally offers available living grounds for plants and animals. On the other hand, urban environments can provide important habitats for species and can have the potential to maintain a higher species richness than intensively managed agricultural habitats (Baldock et al., 2015). This higher biodiversity in urban areas is usually caused by the introduction of nonnative species that replace native species faster than they are lost (McKinney, 2002).

Biodiversity conservation in cities is important for several reasons. First of all, urban areas can support endemic native species and other species that are threatened (Ives et al., 2016; Lepczyk et al., 2017). Ives *et al*. (2016) showed that cities contain more threatened species per unit area than non-urban areas. Secondly, nearly half of the world's people live in urban areas and are increasingly disconnected from nature. This disconnection could result in a lower level of engagement from people towards biodiversity conservation (Miller, 2005). Furthermore, many studies showed that urban biodiversity enhances human wellbeing, where a loss of biodiversity in urban areas negatively affected the life of city dwellers (Botzat et al., 2016; de Vries et al., 2009, 2003; Hartig et al., 2014; Sugiyama et al., 2008).

The potential of urban environments for biodiversity is widely recognized and has caused an increasing interest on the part of (landscape) architects, planners and urban designers to construct more nature-inclusive urban developments to enhance biodiversity in cities (Beatley and Newman, 2013). 'Nature-inclusive urban developments' are developments in which nature and natural elements in the design of, for example a building, plot, street or on neighborhoods scale of urban areas are included. By incorporating nature or natural elements, it ensures that the landscape design contributes to the biodiversity in urban areas.

Nowadays, biodiversity is usually not the main driver when designing a new area or project (Severijnen, 2018; Weisser and Hauck, 2017), and other management goals often conflict with biodiversity goals (Severijnen, 2018). Since landscape architects often do not have the required expertise in the field of ecology, they rely on the knowledge of ecologists to make suitable designs. Therefore, to guarantee the inclusion of nature in the built environment for biodiversity purposes, an interdisciplinary approach with (landscape) architects, urban planners and ecologists is required (Apfelbeck et al., 2020). The communication and knowledge gap between (landscape) architects and ecologists needs to be closed if we want to include nature into the urban development successfully. Besides, the interaction between urban development and how this affects biodiversity is still scarcely understood. Given that more than half of the global populations live in urban areas and is predicted to grow in the future (Ziter, 2016), bridging the disciplines of (landscape) architecture and ecology is crucial to effectively implement nature-inclusive urban development.

In this review, the current state of the academic literature on nature-inclusive urban development (NIUD) will be reviewed. The report starts with outlining the general concept and level of urbanization, worldwide and in the Netherlands, and their consequences on biodiversity and nature experience (chapter 2). Then, principles and main arguments to include nature-inclusive urban development to provide a clear basis for further exploration will be outlined (chapter 3). Following, to illustrate what NIUD could offer based upon scientific evidence, different spatial scenarios that range of development options to include nature in the development of urban areas are proposed (chapter 4). These scenarios are inspired by the action perspective of urban developers to deal with nature in their projects. To accomplish these spatial scenarios to include nature in the urban development, different measures of NIUD can be used. So, following, the evidence regarding the effectiveness of nature-inclusive urban development measures for wildlife conservation will be addressed (chapter 5). At last, the measures of nature-inclusive urban development will be linked to the different spatial scenarios to investigate what the evidence-based effectiveness of the different scenarios is (chapter 6). These research questions are also shown in box 1.

The goal of this project is not to provide detailed information about the different NIUD measures and their required conditions, but to provide a broad overview of the current state and knowledge about nature-inclusive urban development. By providing an overview of the current scientific knowledge and evidence about nature-inclusive urban development, (landscape) architects and urban planners can use this evidence-based knowledge in practice. Most literature used in this review were key publications and review studies. It is important to note that a city consist of multiple different zones. Commonly defined zones in cities include residential areas, commercial areas, industrial areas and spatial areas (e.g., sport complexes, airports, power plants). To limit the scope, this review focusses on the residential area of cities.

Box 1: Research questions

1. What are the main arguments to include nature in urban development?
2. What spatial scenarios for nature-inclusive urban development can be defined that illustrate the range of development options?
3. What is the evidence regarding the effectiveness of nature-inclusive urban development measures for wildlife conservation?
4. Based upon literature (#3), what would the different scenarios (#2) yield for biodiversity conservation?

2. Urbanization

Urbanization alters the built environment, where formerly rural environments are transformed in urban settlements, caused by a shift of the spatial distribution of populations from rural to urban areas. A consequence of urbanization is the increase in number, land area and population size of urban settlements (UN, 2018).

Different forms of urbanization are classified based on the historic growth and planning methods. Different forms of urbanization include *suburbanization*, *counterurbanization* and *reurbanization*. These different forms of urbanization can occur consecutively and are described in the cyclical urbanization model. The first stage described in the cyclical urbanization model is *urbanization* where a mainly agricultural society transforms in an industrial society (Gardlund, 1942; Nystrom, 1992). The second stage is *suburbanization* and it is referred to as one of the further developments of the industrial era. The third stage, *suburbanization*, is described as the expansion of residential areas outwards. Finally, *counterurbanization* (or *desurbanization*) is defined by people migrating from urban areas to the surrounding rural areas (Champion, 2001). The migration out of urban areas is often a result of inconveniences experienced due to defects in infrastructure and transport systems, as well as overcrowding and environmental problems (van den Berg et al., 1982).

2.1. Urbanization worldwide and in the Netherlands

Although cities cover less than 3% of the Earth's terrestrial surface (Aronson et al., 2014), nowadays more people live in urban areas (55%) than in rural areas (45%) (UN, 2018). The level of urbanization differs across different geographic regions. In Northern America 82% of the population lives in urban areas, in Latin America and in the Caribbean 81%, in Europe 74%, in Oceania 68%, in Asia 50% and in Africa 43% (UN, 2018). While in 1950 only 30% of the world's population lived in urban areas, it is expected that in 2050 68% of the world's population will live in cities (UN, 2018). The global urban population is expected to grow with 2.5 billion urban dwellers between 2018 and 2050, with largest increases (90%) concentrated in Asia and Africa.

In the Netherlands, urban areas and their populations are also increasing (Centraal Bureau voor de Statistiek, 2016). Most of the urban areas of the Netherlands are concentrated in the west of the country, the so-called Randstad, a loose conurbation consisting of Amsterdam, Rotterdam, Den Haag, Utrecht and smaller cities in between. Half of the country's population of 17 million lives in the Randstad and 80% of the jobs can be found in the urban areas in the Netherlands (PBL, 2016). A significant population growth is expected in the Netherlands in the coming decade, especially in the four major cities (Amsterdam, Rotterdam, Den Haag and Utrecht). A growth of almost 950 thousand people of the Dutch population is expected between 2015 and 2030 (Centraal Bureau voor de Statistiek, 2016). Of this expected growth, almost three quarters are predicted to take place in the larger municipalities (>100.000 inhabitants). The greatest growth is expected for the four major cities, where 15% more inhabitants are expected in 2030 than reported in 2015. The smaller municipalities will see their population decrease further due to urbanization, especially in Drenthe, Noordoost-Groningen, de Achterhoek, Noord-Limburg en Zeeuws-Vlaanderen (Centraal Bureau voor de Statistiek, 2016).

2.2. Impacts of urbanization on biodiversity

Urbanization has consequences on the biodiversity in urban areas and is one of the leading causes of species extinction (Czech et al., 2000; McKinney, 2006). A review by Czech et al., (2002) even showed that urbanization endangers more species in the United States than other human activities. Cities are characterized by fragmented and disturbed environments, with high densities of artificial structures and impervious surfaces. This causes a decrease in useful areas available for plants and animals to live, and it can cause a selection of specific species. Therefore, urbanization can act as a filtering process selecting only specific species leading to the homogenization of communities (Guetté et al., 2017), resulting in a loss of biodiversity (McKinney, 2008). Moreover, the vegetation in cities is characterized by structural simplification which is negatively correlated with species-richness (Savard et al., 2000). Aronson *et al.* (2014) performed a comparative study between urban and non-urban sites, where they suggested that urbanization has caused a severe decrease in the density of many bird species. This decrease in abundance was best explained as the result of anthropogenic features (urban landcover, city age), rather than by non-anthropogenic factors (geography, climate, topography) (Aronson et al., 2014). Although lower densities have been found, certain bird species appear to have grown in abundance, where they tend to be higher in urban areas compared to the surrounding habitats (Beissinger and Osborne, 1982; McKinney, 2006). Overall, species richness and species diversity is found to be lower in cities than in the surrounding habitats (Beissinger and Osborne, 1982; McKinney, 2006). Nevertheless, urban environments can provide important habitats for species and have the potential to be more biodiverse than intensively managed agricultural habitats (Baldock et al., 2015), usually by the addition of nonnative species that replace native species faster than they are lost (McKinney, 2002).

2.3. Impacts of urbanization on nature experience

A loss of biodiversity in urban areas will impact how nature will be perceived and conserved by future generations. The high use of artificial materials and segregation from natural systems and processes causes a reduced opportunity to interact with and experience nature (Miller, 2005). Over 25 years ago, the lepidopterist Robert M. Pyle termed this ongoing trend the 'extinction of experience'. A review by Soga and Gaston (2016) showed that consequences of this 'extinction of experience' with nature include the deterioration of human wellbeing and that of public health. Where a decrease of opportunities to interact with nature causes a loss of benefits that are associated with human health and well-being. Moreover, the 'extinction of experience' causes a reduced emotional affinity toward nature, including a reduction in interest and love of nature and a reduced motivation to visit and protect nature (Soga and Gaston, 2016). Lastly, the loss of interaction with nature induces a decline in the pro-environmental attitudes and behavior of people. This involves their values, believes and willingness to protect nature. Also, a greater affinity to support and protect biodiversity is found for children who frequently experience nature (Soga et al., 2016). According to Soga *et al.* (2016), children should be encouraged to experience nature and be provided with various types of nature experiences. Figure 1, modified from Soga and Gaston (2016), shows the pathways and feedback loops of the causes (loss of opportunity and affinity) and consequences (emotional, behavioral and attitudinal changes and changes in health and well-being) of the extinction of experience. As shown in Figure 1, the 'extinction of experience' can lead to a feedback loop which can accelerate the consequences of a further loss of interaction with nature (Soga and Gaston, 2016).

> "
>
> *As cities and metastasizing suburbs forsake their natural diversity, and their citizens grow more removed from personal contact with nature, awareness and appreciation retreat. This breeds apathy toward environmental concerns and, inevitably, further degradation of the common habitat….So it goes, on and on, the extinction of experience sucking the life from the land, the intimacy from our connections… people who don't know don't care. What is the extinction of the condor to a child who has never known a wren?*
>
> " *(Pyle, 1993)*

To minimize the 'extinction of experience', opportunities for urban dwellers to interact with nature should be created. Nature can be experienced in different ways and on levels. For, example, urban dwellers can experience nature in the direct living environment by for example the view outside their homes or in their own residential gardens. This will give a different nature experience than, for example, on neighborhood level where residents can experience nature by physical exercise or walking the dog.

Given the substantial benefits of interactions with nature, it is important to mitigate the 'extinction of experience'. There are two ways to limit this estrangement from nature, namely: encourage people to move to locations where contact with nature is more likely, or bring nature to the place where people are already living (Turner et al., 2004).

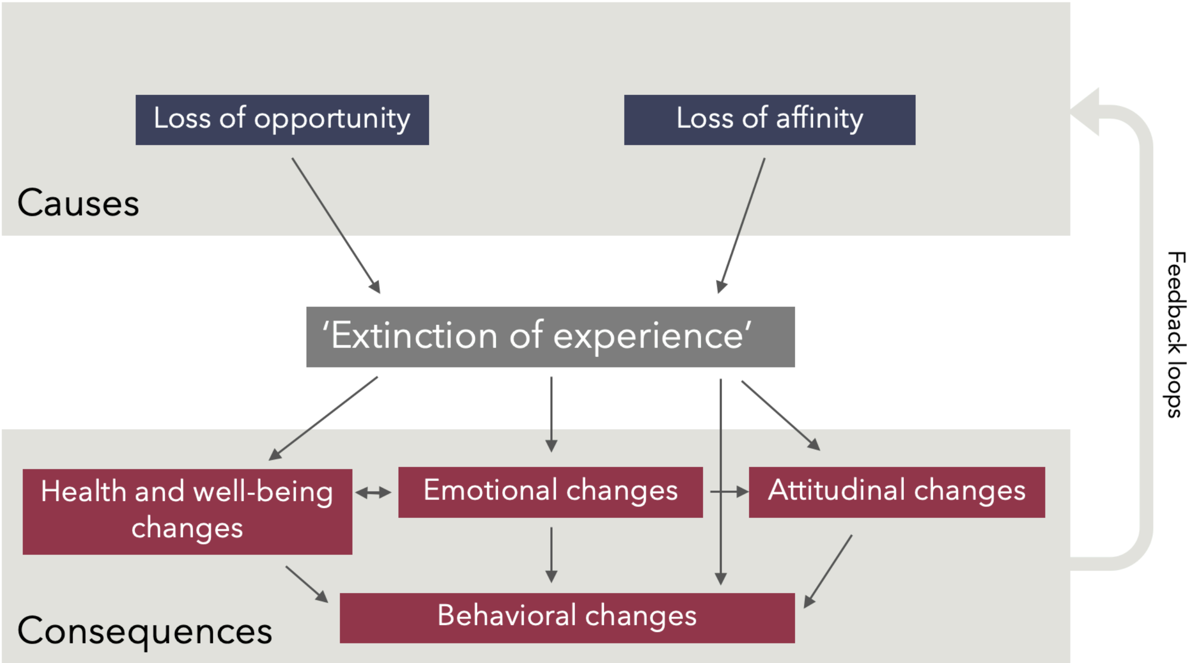

Figure 1; Schematic overview of the causes and consequences of the 'extinction of experience'. (modified from Soga and Gaston, 2016)

3. Nature-inclusive urban development (NIUD)

3.1. Definition of nature-inclusive urban development

The threats that urbanization poses for biodiversity in urban areas can be mitigated by (landscape) architects and urban planners, where the design will be essential in the conservation and protection of landscapes and habitats (Severijnen, 2018). One way to bring nature to cities is by nature-inclusive urban development. Nature-inclusive urban development (NIUD) is a process in which nature is integrated into the design of the built environment to support ecosystem functioning of urban wildlife (Apfelbeck et al., 2020). The design of the built environment must include nature and natural elements to enhance the biodiversity. NIUD can be applied at different scales, such as the building, plot, street and neighborhood level (Apfelbeck et al., 2020; Beatley and Newman, 2013)

3.2. Benefits of nature-inclusive urban development

The goal of NIUD is to introduce nature into the built environment for the conservation of wildlife and ecosystems, but also to increase the opportunity of urban dwellers to interact with nature and decrease the 'extinction of experience'. Next to these benefits, there are other benefits of introducing nature in the built environment, which will be discussed in the next sections.

Human well-being

Firstly, many studies showed that 'urban nature' enhances the livability and has benefits to physical health, psychological wellbeing and social cohesion (de Vries et al., 2003; Maas et al., 2006; Sugiyama et al., 2008). As mentioned before (see chapter 2.3) a loss of interaction with nature causes a loss of benefits for health and well-being. Studies in The Netherlands have shown that the amount of green space in a neighborhood was associated with better perceived general health (de Vries et al., 2003; Maas et al., 2006). A literature review by de Vries *et al.* (2009) and Hartig *et al.* (2014) identified four mechanisms as promising explanations for the positive relations between urban nature and human health and wellbeing. Firstly, urban nature improved the air quality, in particular by capturing of particulate matter and therefore had positive effects on human health. Secondly, urban nature reduces stress and restored concentration capacity, although the long-term effects of nature on stress reduction still need to be investigated. Thirdly, nature may stimulate physical exercise, by offering suitable spaces for certain types of activities. For recreational activities, green areas in the residential environment are generally found to be attractive and used for recreational purposes, most often for walking and cycling (de Vries et al., 2009, 2003). However, this does not mean that people will avoid physical exercise in the absence of urban green. Lastly, social cohesion is found to be higher in areas with urban nature (de Vries et al., 2009; Hartig et al., 2014; Sugiyama et al., 2008).

Water cycle

Secondly, nature in urban areas has a positive influence on the water cycle in a city. Urbanization leads to changes in the surface cover, especially the increase of impermeable surfaces and the removal of vegetation, that disrupt the hydrological cycle in cities. A dense urban area can have more than 90% of its land covered with impermeable or low permeable surfaces (Groth et al., 2016). Since an impermeable surface cannot absorb precipitation, this water flows off surfaces and reduces infiltration into groundwater. Green space in an urban ecosystem performs both water-regulation and water-purification functions (Yang et al., 2015). Besides, urban green space can efficiently reduce surface runoff and it can act as an effective sink for storing and receiving rainwater (Yao et al., 2015). Regulating surface runoff becomes especially important since the projected climate change leads to an increased frequency and intensity of heavy rain events. A study by Yao *et al*. (2015) in Bejing showed that adding 11% of tree canopy, more than 30% of runoff retention is projected.

Cooling

Thirdly, green spaces in cities can be used to mitigate the adverse effects of the 'urban heat island effect', extreme heat events, and climate change effects (Gill et al., 2007; Oliveira et al., 2011). It has long been recognized that cities are typically warmer than the surrounding rural areas; also called the urban heat island effect (Feyisa et al., 2014; Gunawardena et al., 2017; Oliveira et al., 2011). A study by Emmanuela and Loconsole (2015) showed that a green cover increase of approximately 20% could eliminate between a third and a half of the 'urban heat island effect' expected in 2050 and could lead to local reductions in surface temperature of up to 2 ˚C (Emmanuel and Loconsole, 2015). Li *et al*. (2012) found similar results, where a 10% increase of greenspace resulted in approximately a 0.86 °C decrease in land surface temperature. Therefore, one possible adaptation strategy to the increasing temperatures and to the 'urban heat island effect' is to preserve existing areas of greenspace and to increase these areas where possible.

Economic

Finally, next to ecological and health benefits, bringing nature into the built environment can also have economic benefits. First of all, natural areas can allow for (eco)tourism and recreation. Secondly, green areas can increase property values, where in general properties and homes located near green areas have higher values (Hostetler, 2012). Finally, through its positive effects on the water cycle and irrigation, the preservation of green areas can decrease irrigation costs.

4. Scenarios of nature-inclusive urban development

In this chapter, to illustrate what NIUD could offer, different spatial scenarios that range of development options to include nature in the development of urban areas will be proposed. Urban development (or planning) is a technical but also a political process which deals with the design and land use of the built environment in urban areas (Cortinovis and Geneletti, 2019; Newman, 2002). Urban development includes the design and construction of buildings, the infrastructure and the present greenery and giving substance to them. Also, for urban development it is important to include the notion of who it is designed for and what the ultimate goal is. Urban planners need to keep into account what the demand is in an area. For example, is there a growing interest for more commercial areas, residential buildings or more nature incorporation in the area? Alongside, the urban planner needs to consider what the legal requirements are and what is allowed by legislation. At last, the urban planner needs to consider the target audience (e.g., individual urban dweller, municipality etc.) and their requirements.

When nature needs to be incorporated into the design of an area, all of the considerations mentioned above need to be taken into account. Urban planners have to ask themselves the following questions: What is the purpose of integrating nature into the design (e.g., connecting nature area's or satisfy the desire of the urban dwellers)? Who is asking the urban developer to bring nature into the area (target audience)? What is the purpose of the area (e.g., residential or commercial area)? And so on.

Based on these questions, different scenarios can be formulated to explore how nature can be included in the planning phase of the urban developer. These scenarios all have different target areas and groups and therefore purposes as to why nature should be incorporated in urban development. In this report, three possible scenarios will be discussed. These scenarios are selected since they differ greatly from each other, but are common scenarios used in practice. Since these three scenarios have different perspectives on how to incorporate nature into the design these can lead to a completely different outcome and layout of the area, and in turn could lead to different nature integrations.

4.1. Scenario 1: Include nature in direct living environment

The first scenario is inspired on the situation in which project developers would like to offer specific nature-inclusive features at the building and plot level to meet the demand of individual residents for more nature surrounding their homes (Figure 2). It could be a market-driven option, not linked to the overall lay-out of the development nor to fulfill local legislation towards green space planning.

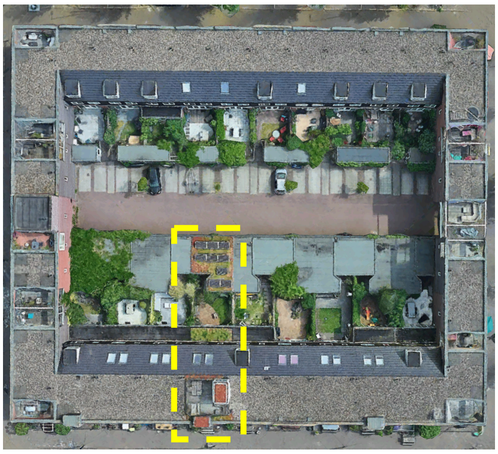

Figure 2; Scenario 1. Include nature in the direct living environment of the urban dweller.

4.2. Scenario 2: Create a biodiverse habitat on community level

The second scenario is to illustrate the situation in which a project developer could accommodate a resident community that specifically appreciate nature as key condition for their living environment (Figure 3). Despite it seems a niche market there seems to be a tendency that more and more people would like to live in surrounding where nature is included in the design of a neighborhood or block.

Figure 3; Scenario 2. Create a biodiverse habitat on community level.

4.3. Scenario 3: Create a built environment that is part of the surrounding area

The third scenario is to create a built environment that is part of the surrounding area (Figure 4). This is a demand that is often asked the urban developer by the municipality. The municipality wants to connect green areas (e.g., parks or surrounding green areas) to allow nature to migrate thought the area. The urban developer can provide measures in the design of the area to allow this migration.

Figure 4; Scenario 3. Create a built environment that is part of the surrounding area, to allow nature to migrate through the area.

To make a decision for an urban development scenario, based on the target groups requirements for nature inclusion, a comparison between the different scenarios should be made. For this comparison, information is needed on what the advantages and disadvantages are of the different scenarios. But to determine which scenario is best for a certain urban development construction, more information is needed on which different measures can be taken to accomplish these scenarios.

5. Evidence on measures of nature-inclusive urban development

Nature-inclusive urban development can be applied to various types of works and at different scales such as the building, block, street and neighborhood (Figure 5). In the next part of this report, different measures will be discussed that can be incorporated at different levels and on different species groups to investigate which measures are evidence based and where is more research needed.

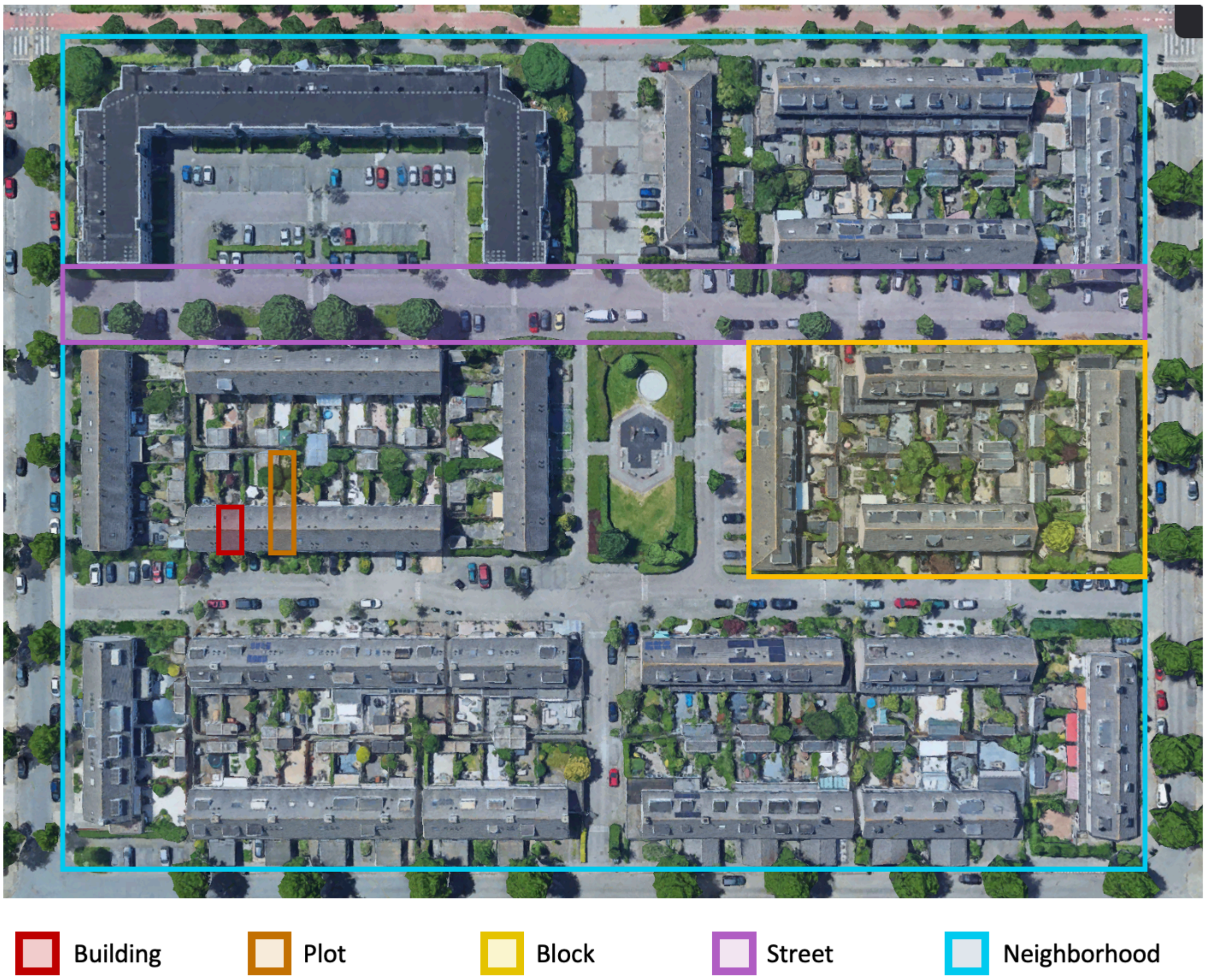

Figure 5; Different levels that nature-inclusive urban development can be applied to.

5.1. Building level

In the next sections, different measures of NIUD that can be applied on building level will be discussed. Measures that will be discussed are “green roofs”, “green walls” and “nesting boxes.

5.1.1. Green roofs

A green roof, also known as a vegetated roof, living roof or eco roof, is a roof of a building that is partially or completely covered with vegetation. Green roofs can be categorized as ‘‘intensive’’ or ‘‘extensive’’, depending on the plant material and the planned usage for the roof area (Getter and Rowe, 2006) (Figure 7, Figure 6). Extensive green roofs are characterized by their low weight, minimum maintenance and low installation costs. Extensive green roofs are generally made up of a thin layer of soil (often under 150mm) with shallow-root plants like sedums, small grasses, herbs and flowering herbaceous plants, which need little maintenance and no permanent irrigation system. Intensive green roofs (often referred to as roof gardens) are so named because of their ‘‘intense’’ maintenance needs. They require deep soil (often over 150 mm) and accommodate all types of plants including large shrubs and trees.

Figure 7; Intensive green roof

Figure 6; Extensive green roof

The use of green roofs has several benefits. One of the greatest advantages that green roofs provide is the reduction of the amount of stormwater runoff and the delay of stormwater runoff when the green roof is saturated (Getter and Rowe, 2006; Stovin, 2010). Next to that, green roofs provide building insulation and shade, thus saving energy consumption (Banting et al., 2005; Getter and Rowe, 2006; Niachou et al., 2001; Wong et al., 2003) and reducing the urban heat island effect (Banting et al., 2005; Getter and Rowe, 2006). Moreover, green roofs filter harmful pollutants and therefore improve the air quality of the city (Banting et al., 2005).

Since most green roofs are inaccessible to the public, they can provide an undisturbed habitat for microorganisms, insects, and birds. Therefore, green roofs can enhance the biodiversity (English Nature, 2003; Getter and Rowe, 2006). Moreover, green roofs are highly likely to provide habitat for a greater abundance and diversity of both plant and animal taxa (Tonietto et al., 2011) then conventional roofs (Dunnett, 2006). Biodiversity can be enhanced by green roofs by providing new habitats in areas where wildlife habitat is lacking, by facilitating movement in a network of habitats, or by providing additional and important habitats for rare or protected species (English Nature, 2003). Williams *et al*. (2014) performed a literature review and showed that a great variety of taxa had conservational benefits from green roofs including native plants, birds, reptiles, mammals, bees, butterflies and moths, spiders, beetles, grasshoppers and flies.

Although green roofs are colonized by more species than conventional roofs, most reports do not identify whether colonizing plant species are native or exotic (Williams et al., 2014). However, Madre *et al*. (2014) did an extensive survey of 115 green roofs in northern France and showed that colonizing plant communities on green roofs are mainly composed of common urban species (native) but also of species with protected status and xero-thermophilic species with a high light affinity. Madre *et al*. (2014) showed that substrate depth is the most important factor structuring the wild plant diversity on green roofs, next to green roof age, surface area maintenance intensity and building height. Moreover, wild plants could have an important role in green roof ecosystems, since they are generally native and they could serve as a food chain basis for local pollinators, such as bees (Tonietto et al., 2011).

A study by Tonietto *et al*. (2011) showed that green roofs can act as both a foraging place but also a nesting place for pollinating insects. However, green roofs with greater (blooming) plant diversity generally have greater bee diversity (Tonietto et al., 2011). This greater diversity in (blooming) plants provides a greater variety of foraging resources to attract a greater variety of bee species. Therefore, green roofs with diverse (native) species, rather than monotypes of *Sedum* used in extensive green roofs, would increase the value for bee conservation. Next to the possibility of green roofs to act as foraging places, bees can utilize green roof substrates for nesting. Tonietto *et al*. (2011) showed that green roofs that consist of one to several layers of small slate pebbles with a high proportion of sand, can provide a suitable nesting substrate for bees. However, lower bee diversity and abundance on green roofs are reported compared with ground level (Tonietto et al., 2011).

Next to bees being present in green roof habitats, a wide variety of other insects can colonize green roofs. Green roofs are an important way to restore habitat and are colonized by numerous insects including spiders, beetles, ants, bugs and bees (Fernandez-Canero and Gonzalez-Redondo, 2010). In the past, researchers believed that only the most mobile species could colonize green roofs, however, MacIvor and Lundholm (2011) showed that also medium, large and even flightless insects can colonize (intensive) green roofs. MacIvor & Lundholm (2011) discovered slightly greater levels of insect diversity and abundance in ground-level habitats compared to adjacent one- and two-story green roofs.

The presence of insects on green roofs can increase the availability of food for birds and it is shown that the main reason for birds to visit green roofs was to forage (Fernandez-Canero and Gonzalez-Redondo, 2010). Next to the availability of food on green roofs for birds, another habitat function of green roofs in the provision of nesting sites for nesting birds (Brenneisen, 2006). Green roofs can be better habitats than conventional roofs for birds mainly due to the cover offered by plants (Fernandez-Canero and Gonzalez-Redondo, 2010).

Green roofs can also offer interesting foraging habitats for mammals such as bats. Previous research on bat activity on conventional roofs, '*Sedum'* (extensive) roofs and 'biodiverse' (intensive) roofs showed that bat activity (=foraging activity) was significantly higher over biodiverse roofs compared to conventional roofs (Pearce and Walters, 2012). However, no significant differences in bat activity was found between sedum and conventional roofs. These results suggest that (intensive) biodiverse roofs offer enhanced habitat for bats in urban areas (Pearce and Walters, 2012).

Up to now, far too little attention has been paid to the comparisons between biodiversity levels of green rooftops and ground-levels, therefore no big conclusions can be drawn if green roofs can support that same species diversity, composition and abundances of organisms comparable to ground-level habitats (Williams et al., 2014). Besides, it should be noted that the elevation of the green roof will strongly influence the use of a green roof habitat. When the elevation of the green roof is too high, the habitat can become isolated which makes it inaccessible to some low-mobility species (that cannot fly, be dispersed by wind or can climb up to the green roof) (Williams et al., 2014). Therefore, if green roofs are designed on high elevated buildings, it is necessary to provide connectivity with adjacent habitats.

Furthermore, green roofs are artificial systems where the typical *Sedum*-dominated green roofs are often habitats more closely resemble the sort of vegetation that naturally occurs on cliffs, rocks and scree slopes, which does not support a great variety of different species (Lundholm, 2005). These habitats may not typically be present in the area, which means that the newly formed green roof habitat does not relate to the nature in the surrounding environment. This causes that green roofs can provide very important habitats for specialists, endangered species and rare species (Williams et al., 2014). However, this also means that if a standard *Sedum*-dominated green roof is placed on a roof in an area that does not naturally support these habitats, it is possible that local and native species may not migrate to these new habitats. This raises the question if green roofs that are designed specifically to support native organisms support a greater species diversity and abundance of organisms than standard *Sedum*-dominated green roofs. First of all, habitat heterogeneity should support a greater biodiversity (Tews et al., 2004; Williams et al., 2014). Green roofs that support a greater heterogeneity and with the use of native species are called 'biodiverse roofs' (also called 'biodiversity roofs' or 'green roofs for biodiversity'). With the use of local or native plant species, the most frequently made argument is that they can support a greater number of other wildlife species in that area than non-native species, because of co-adaptation, and thus support more feeding invertebrates and be better for biodiversity (Dunnett, 2006). However, this does not mean that the conservation value of non-native species in negligible, since they can fill an important gap or food source at the time when natives are not blooming (Dunnett, 2006). Next to the use of local plant species, biodiverse roofs can use the local characteristics of plant communities and use local materials such as seed, plants and even soils and substrate materials to replicate the local plant communities and habitats. However, it is important to mention that the chemical, physical and biological characteristics of a soil are altered as soon as it is disturbed and that it can take hundreds or thousands of years to reestablish the same habitat in the soil (Hostetler, 2012). Although 'biodiverse roofs' are getting more recognition, there remain few empirical comparisons between 'biodiverse roofs' and typical *Sedum*-dominated green roofs. Therefore, more research is required to confirm if 'biodiverse roofs' indeed support a greater diversity and abundance of organisms than standard green roofs.

5.1.2. *Green walls*

Another strategy to include nature into the development of urban areas is with the use of 'green walls' (also called living walls or green facades). Green walls is the most general term used to define all forms of vegetated wall surfaces (Manso and Castro-Gomes, 2015). Green walls are made of climbing plants growing on a wall, either with or without additional infrastructure for support. The term 'green walls' groups different types of greening techniques where we can divide green walls in three common techniques: 1) self-adhesive climbing plant façades, where climbing plants are directly growing on the façade, 2) climbing plants on supporting structure, where climbing plants do not grow directly on the façade but instead on a supporting structure and 3) modular green walls. Modular green walls are façades that are placed in front of the wall of the building made up of boxes or cassettes (Figure 8). Contrary to the climbing plant facades the roots of the plants in modular green walls do not take root on ground level.

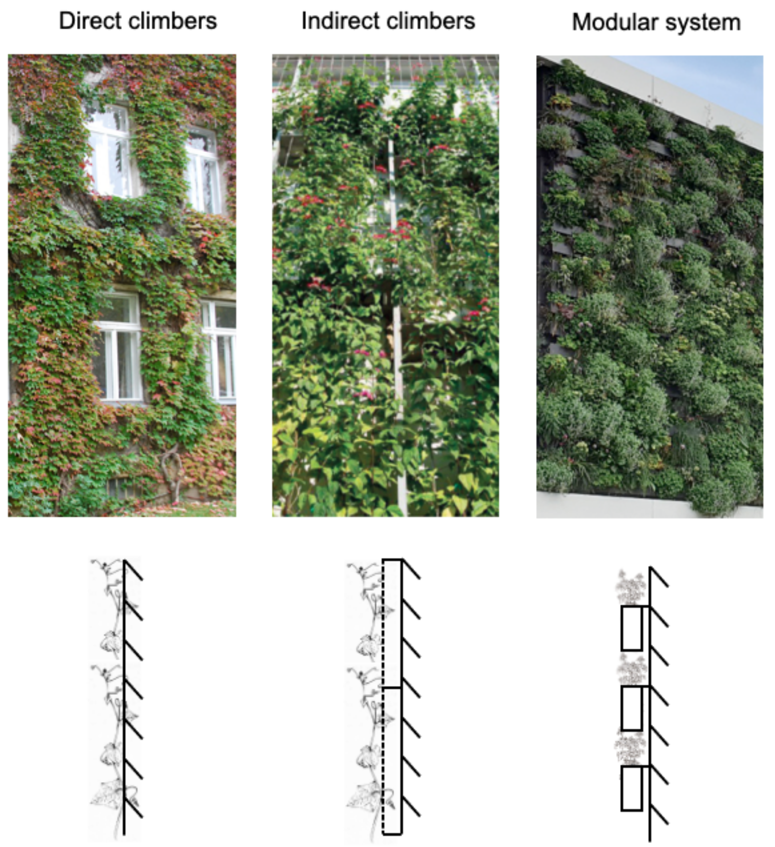

Figure 8; Three most common climbing wall techniques

Green walls offer a great number of benefits which can be motivations for their installation. First of all, green walls can have important effects on the temperature, insulation and energy consumption of buildings (Wong et al., 2009). Secondly, vegetated façades can enhance air quality by capturing harmful pollutants (Madre et al., 2015; Pugh et al., 2012). Moreover, green walls can reduce storm-water flows (Roehr and Laurenz, 2008) and protects walls from degradation due to harsh environmental conditions (e.g., sun and acid rain) (Köhler, 2008). However, currently one of the main drivers for urban planners to integrate green walls into the design of a building is because of their enhancement in the aesthetic value of a building (Madre et al., 2015). Next to all the beneficial effects of green walls it is also important to refer that some climbing plats can damage building surfaces, destroying it with their roots and entering voids or crack. Therefore, this should be taken into account into the design phase of a building to prevent this disadvantage.

The different types of green walls have shown to offer different habitats. Madre *et al.* (2015) showed that climbing plant façades show similar habitats to cliffs where modular façades are more damp and cool habitats, which are more similar to vegetated waterfalls (Madre et al., 2015). Since these different types of green walls offer different habitats, they have an effect on the ecological characteristics and flora and fauna properties. However, only a few studies have investigated the ecology of these green walls and wall ecology is still considered as a frontier in urban ecology (Francis, 2011). Nevertheless, green walls can perhaps have a greater potential than green roofs considering that the surface of façade greening in urban areas can be double the ground footprint of buildings (Manso and Castro-Gomes, 2015).

Walls can be habitats for climbing plants, which can grow up the wall directly thought adhesive pads ("direct climbers") or grow up the wall by twining around on supporting structures ("indirect climbers). Under temperate climate, the most used climbing plants are light to shade-tolerant, with the genera *Hedera* as the most well-known, making them suitable in urban areas where light exposure is conditioned by architecture (Mayrand et al., 2018). Spontaneous wild flora in green walls are mainly native, common and similar to the ground-level ruderal greenery systems and clearings (Mayrand et al., 2018). Green walls can host a great variety of plants. Plants species can be epiphetic, lithophetic but also grasses, shrubs, ferns, succulents, herbaceous plants, climbing plants, ornamentals, vegetables, herbs and berries are also possible if their species critical factors (e.g., water and nutritional needs) are met (El Ghomari, 2019; Manso and Castro-Gomes, 2015).

Overall green walls shelter more diverse fauna than bare walls (Mayrand et al., 2018). Chiquet *et al.* (2013) investigated bird activity on green walls and showed that birds are more abundant on green walls compared to bare walls. It appears that green walls are most valuable for birds during winter, where evergreen species are most attractive (since they provide shelter, provide a source of heat and protection from wind) (Chiquet et al., 2013). Moreover, birds exploit green walls for various reasons, including nesting, food and shelter. The reason why birds use the green wall depends on the resources which are available. While some species use the green walls for nesting withing the wall vegetation, other species may use it for food (e.g., invertebrates in the wall) (Chiquet et al., 2013).

Invertebrates also use green walls as an alternative habitat. Green walls offer habitats for generalist, common but also rare and specialist species (Mayrand et al., 2018). Good dispersers, such as winged insects and species that are carried by the wind (e.g., spiders), are overrepresented on green walls (Mayrand et al., 2018). Assemblages of spiders are dominated by generalist species (Madre et al., 2015). As mentioned before, there are different greening techniques for green walls, which cause local scale differences (e.g., microclimatic or floristic properties). These differences influence he properties of arthropod assemblages. Overall green walls provide higher arthropod species diversity compared to bare walls (Madre et al., 2015). However, modular green walls in turn provide higher species diversity than climbing plant façades. This could be explained by the fact that modular systems provide a more structurally diverse habitat (from shrubs to substrate) than climbing plant facades (Madre et al., 2015).

Green walls are also visited by pollinators (e.g., honeybees, bumble bees, bristly flies, and butterflies) for resources, such as nectar and pollen (Mayrand et al., 2018). However, the pollinator abundance and community structure depends on the number of floral species and their associated nectar and pollen profiles (Potts et al., 2003). Therefore, using green walls to increase floral abundance and diversity in urban areas could benefit pollinators (El Ghomari, 2019). Literature is scarce regarding the most beneficial floral species for pollinators, but a study by El Gomhari (2019) noted some crossover favorable pollinator species and species that are already used in green walls. These include *Origanum vulgare* and *Echium vulgare* and the *Stachys*, *Erysimum*, *Trifolium* and *Lavandula* genera. In particular, native wildflowers were found to be important for pollinating insects (El Ghomari, 2019). Next to food resources, pollinators also need nesting sites to complete their life cycle. No research has been found that green walls offer nesting opportunities for pollinators, but artificial nesting sites can be included within the green walls.

Mammals (e.g., bats and mice) are likely to exploit walls but too few studies investigated these taxa (Johnston and Newton, 2004).

5.1.3. Nesting boxes

5.1.3.1. Birds

Some bird species (e.g., common swift, house sparrow) that breed in urban areas are dependent of permanent nesting sites in buildings (Gemeente Amsterdam, 2020). Many city bird species populations in the Netherlands are declining (Centraal Bureau voor de Statistiek, 2018), and especially House Sparrows are in serious decline in urban areas in Western-Europe over recent decades. In the Netherlands, the decline is apparent from 1990 onwards, which resulted in the addition of the House sparrow to the Red List of threatened birds. Some bird species, including the House sparrow use cavities in buildings as nesting sites. A shortage of available nesting sites may be one of the reasons for declines in city bird species and it may be the case that modern houses provide fewer nesting opportunities (Balaji, 2014). Nesting stones for birds can be attached (visible or invisible) to the façade of a building or construction (Figure 9). Each bird species has their own specific design for nesting stones. Nesting stones could potentially offer more nesting sites for city bird species. However, research is scarce about the use of artificial nests by birds and should be more intensively studied to actually uncover if nesting boxes can slow or stop the decrease of urban bird species.


Figure 9; Nesting stone for birds

The use of artificial nests varies per species and there is a lot of variation in how often these artificial nesting sites are used by specific target species. The percentage of the population that uses artificial nesting sites varies from <30% (e.g., House sparrow, Common swift) up to more than 70% by the Peregrine falcon (Goffin, 2019). A literature review performed by Goffin (2019) investigated the effect of artificial nesting sites on the population of ten Dutch breeding bird species (Peregrine falcon, Common kestrel, Barn owl, Little owl, Common swift, Common house martin, European starling, Great tit, Eurasian blue tit and the House sparrow). The effect of artificial nesting paces appears to be positive in many cases, especially for the Peregrine falcon, common kestrel and barn owl, but also for the little owl, common swift, common house martin, great tit and blue tit. No to little disadvantages are found for use of artificial nests by bird species. Higher breeding success is found for most species in artificial nests compared to natural nests. It is also possible that the provisioning of artificial nest for one target species also increased the breeding success of other non-targeted species. However, most of the studies that investigated the effect of artificial nesting sites on these bird populations were local studies. More research needs to be performed on the country-wide level of the use of artificial nests.

5.1.3.2. Bats

Figure 10; Nesting stone for bats

Next to stones that are designed for birds, bat boxes can be installed on or in a building to provide shelter for bats (Figure 10). Bats are a vital part of our native wildlife, and provide a range of key ecosystem services (e.g., arthropod suppression, seed dispersal and pollination) (Kunz et al., 2011). After the Second World war, the number of bats were reduced because of changing landscapes and land use (van der Mei and Dijkstra, 2011). Therefore, since 2002 all European bat species are protected under the European Habitat Directive which provides directive for protecting bat populations and their habitats (van der Mei and Dijkstra, 2011). One of the reasons that the urban environment is less attractive to bats is because of a lack of vegetations, which results in a shortage of insects for bats to feed on. Besides, the loss of trees that contain cavities, which provide potential roost or nest sides for bats, makes urban areas less attractive to bats (Rueegger, 2016). One of the solutions is to provide roosting and shelter opportunities for bats is by installing bat boxes into the design of a building.

Artificial roosts can provide protection from weather and predators and offer a place for nesting and breeding (Mering and Chambers, 2014). Although artificial roosts have been widely used, information on species that use the artificial roosts, the design and the placement is poorly documented. There is a range of different box sizes, shapes and construction materials, however, artificial roosts should be constructed and installed to mimic the natural roosts, emphasize the requirements of the target species and exclude non-target species (Mering and Chambers, 2014). There are three important factors that influence the use of artificial roosts: 1) characteristics of natural roost, 2) design of the artificial roost and 3) the species that are present in the local bat community composition (Mering and Chambers, 2014). By taking these factors into account, species-specific boxes can be designed that are species-specific. Nowadays, bat box designs are typically not species-specific, while not all bat species are found to use the provided bat boxes (Griffiths et al., 2020). Bat communities in urban landscapes are dominated by disturbance adapted, generalist species (Russo and Ancillotto, 2015). These generalist species are also more likely to roost in artificial nesting structures than bat species with more specialized roosting requirements (Russo and Ancillotto, 2015). This causes the concern that installing bat boxes could cause a shift towards a less diverse bat community, with higher abundances of generalist species. A study by Griffith *et al*. (2020) investigated this concern and showed that bat boxes might not cause this community shift in local community composition level in the short- to medium term, however, further research should be conducted to test these community shifts on the long-term.

5.1.3.3. Insects

There are multiple nesting boxes designed for insects, also called insect hotels. One example of a nesting box for insects is a nest box designed for pollinators such as bees (Figure 11). With urbanization (habitat loss and fragmentation), pollinators are under threat and populations are declining (El Ghomari, 2019). Although urbanization can cause local species extinction, many bee species persist in urbanized areas. (Fortel et al., 2016). Pollinators are vital for natural ecosystems. Insect-pollinated plants are important for biodiversity since they provide food, shelter and other resources to birds, mammals and other insects (Breeze et al., 2012). Much attention has focused on improving the floral resources available for bees, while little attention has been paid to nesting resources. To support urban pollinators, it is also important to provide nesting sites. An example of a pollinator nesting side is the artificial bees nesting box (Figure 11). Although most bees nest in the ground, more and more effort has been taken the last years in installing artificial nest boxes which artificially provide nest sites of above ground nesting bees. These bees boxes are usually made from bundles of plant stems, paper-based tubes, or holes drilled in wood (MacIvor and Packer, 2015). A number of wild bee species have been shown to use artificial nesting structures such as bee hotels (Fortel et al., 2016). However, there is very little evidence of the usefulness of bee hotels as tools to help the conservation of wild bees within cities.

Figure 11; Nesting box for bees

5.2. Plot level

Scaling up from building level is the plot level. A plot is the land on which the building is located, that may be combined with a garden surrounding by the building. In the residential area of a city this green around a building on plot level is usually private green. Therefore, the plot level can be defined as the building together with private green. In the next section the use of private gardens as a measure for nature-inclusive urban development will be discussed.

5.2.1. Private gardens (on plot level)

Private gardens collectively comprise the largest green space in urban areas and have a great potential for increasing biodiversity and provide opportunities for urban dwellers to reconnect with nature. Besides, gardens can act as important stepping stones in the ecological network of a city. However, gardens remain the least studied and least understood habitat in urban areas. Despite the growing awareness of the conservation potential of private gardens, little is known about the biodiversity and species composition and dynamics in private gardens. Seemingly, this is because private gardens lie outside the control of local governments and authorities (Goddard et al., 2010) and the contribution of gardens to neighborhood or city-wide biodiversity is largely a product of many individual decisions.

The plant composition in European-style private gardens differs from the native bushland habitat (Cannon, 1999). Some short-term studies have been undertaken but most research has been conducted in the Biodiversity in Urban Gardens in Sheffield project (BUGS project). In this project, floral surveys were performed in six cities in the UK (Sheffield, Leicester, Belfast, Cardiff, Oxford and Edinburgh), comprising of approximately 50 gardens of all types and sizes in each city. This project demonstrated that private gardens can support a rich plant and invertebrate biodiversity (Richard M. Smith et al., 2006b; R.M. Smith et al., 2006). Besides, a very high proportion of plant species in private gardens is found to be exotic. In the UK 70% of the plants in the average garden is found to be non-native (Goddard et al., 2010; R.M. Smith et al., 2006). This high amount of non-native plants has consequences on the surrounding areas. Exotic plants can escape from private gardens and cause ecological, economical and conservation impacts (Goddard et al., 2010).

Next to investigating plant diversity in the BUGS project, the BUGS project sampled 70 gardens of all types, sizes and locations for their invertebrate diversity. After which various comparisons were made between the amount of diversity found in the gardens and different variables such as the size of the garden, the location, intensity of management and if there were a lot of native or non-native plants present in the gardens. It is often assumed that native plants are superior to introduced plant species and provide the best resources for biodiversity (Kendle and Rose, 2000; Salisbury et al., 2015), however, this seems not always to be the case. The results from the BUGS project showed that invertebrate abundance and species richness are mostly explained by plant structural heterogeneity and taxonomic diversity rather than native or non-native status (Richard M. Smith et al., 2006b, 2006a).

Floral species in private gardens can provide food resources (nectar and pollen) for pollinating insects. Previous research has shown that the greater the resource availability (more flowering plants) the more pollinators will visit the private garden (Salisbury et al., 2015). Assemblages of native and near-native garden flowering plants had the greatest abundance of pollinators compared to exotic plants (Fukase, 2016; Salisbury et al., 2015). Although native flowering plants are preferred by pollinators, exotic plants can extend the flowering season and provide additional resources when native or near-native plant abundances are low. Therefore, a variety of flowering plants with a higher abundance of native and near-native plants and some exotic flowering plants are recommended in private gardens to extend flowering season and provide resources.

Most gardens support a reduced number of avifauna, caused by a variety of factors including: high levels of disturbance, lack of nesting opportunities, predation and exotic plant species (Cannon, 1999; Cannon et al., 2005). However, there are also many bird species that nest in urban areas, with private gardens holding significant populations (Bland et al., 2004; Chamberlain et al., 2009). The characteristics of the garden itself affects the bird species richness, assemblage and abundances, suggesting that the gardener can substantially influence the bird species composition (Daniels and Kirkpatrick, 2006). Previous research showed that birds species richness is positively correlated with native plant biomass (Day, 1995). Furthermore, native bird species show a preference for native plant species in private gardens, whereas exotic birds are more dependent on introduced plant species (Daniels and Kirkpatrick, 2006; Day, 1995; van Heezik et al., 2013). Another factor that is important to attract garden birds is cover (large and small shrubs, but also trees), which represent a resource of food, nesting, shelter and protection from predators all year round (Chamberlain et al., 2004; Daniels and Kirkpatrick, 2006; van Heezik et al., 2013). Moreover, bird species richness in private gardens is affected by the tree species composition. In Europe, the highest bird species richness is found in gardens with both deciduous and coniferous trees (Thompson et al., 1993). Gardens with only deciduous trees appear to have lower bird species richness, than when both deciduous trees and conifers are present, and gardens with only conifers show the lowest bird species richness (Thompson et al., 1993). Lastly, clumped trees result in a higher species abundance per unit area than dispersed trees (Day, 1995). Another factor that has a substantial effect on bird species richness is the size of the garden and the area covered by vegetation. Birds species richness in private gardens is positively associated with the area covered by vegetation (van Heezik et al., 2013) and, furthermore, a bigger garden area has a positive influence on garden bird species richness (Chamberlain et al., 2004; Thompson et al., 1993)

Residential gardens represent a habitat that may be suitable for small mammal species, as they offer a wide variety of microhabitats and food sources. Since residential gardens are private property, research is scarce on the use of private gardens by mammals. However, gardens can offer a refuge for native mammals and garden habitats may mitigate the effects of urbanization for some mammal wildlife (Van Helden et al., 2020). A study by Baker and Harris (2007) showed that mammals (e.g., bats, hedgehog, mice, mole, rabbit, vole) appeared to be affected by garden size and garden structure, but to differing degrees. Garden use by mammals increased with decreasing urbanization, which is related to reduced human disturbances, traffic flow and garden size (Baker and Harris, 2007). Nevertheless, the proximity to natural and semi-natural habitats seems to be of more importance than a lower urbanization level (Baker and Harris, 2007). The ability of animals to use urban private gardens is influenced by both behavioral traits (e.g., temperament, behavioral plasticity) and environmental factors (e.g., vegetation structure, (floristic) species diversity) (Van Helden et al., 2020). However, it should be noted that also other factors, like supplementary feeding, also plays an important role. The characteristics that predict mammal presence in urban gardens if often species-specific (Baker and Harris, 2007). For example, vegetation cover (shrubs, trees) can be an important factor if this corresponds to their natural habitat dependencies of a certain species (Van Helden et al., 2020). Moreover, Van Helden *et al.* (2020) showed that even the characteristics that predict mammal presence differed between regions, which suggests that garden features cannot be generalized among cities. Other factors that can explain the variation in presence of mammal species in gardens include variation in the abundance of the animal population, the age of the city development and climatic variations (Van Helden et al., 2020). However, there is no empirical research done on these factors. To successfully exploit the opportunity that private urban gardens can offer for mammal wildlife conservation, species-specific research to the garden features that encourage the use by animals need to be performed. Moreover, increased community awareness and participation is required (Van Helden et al., 2020).

Next to the potential biodiversity advantages, private gardens and gardening also have multiple human benefits. First of all, private gardens form the primary interface to the natural environment for many people. Therefore, private gardens can enhance the nature experience of urban dwellers. A study by Dunnett and Qasim (2000) showed that many urban dwellers valued their private gardens as giving them contact with nature. Besides, next to the personal satisfaction and stress relieve, private gardens offer the opportunity to enhance individual creativity (Dunnett and Qasim, 2000). Moreover, private gardens offer possibilities for physical exercise, although this varies with the gardens size and features contained within it (Dunnett and Qasim, 2000).. At last, gardens can encourage neighbors to meet which enhances the community connectivity. However, as mentioned before, gardens remain the least studies and least understood habitat in urban areas. This also includes studies about (stormwater)runoff and water management. However, more general knowledge based on larger scale greenery could also be applied to private gardens. It is known that an increase of groundwater recharge is associated with the high permeability of green areas, including gardens, compared to high impermeable surfaces (Groth et al., 2016). Besides, a study by Warhurst *et al.* (2014) showed that an increase of impermeable surfaces in front gardens increased the flooding frequency. However, previous research showed that green spaces can be used to mitigate the adverse effects of the urban heat island effect (Gill et al., 2007; Oliveira et al., 2011). Since private gardens collectively comprise the largest green space in urban areas, they have a great potential to mitigate the Urban Heat Island effect.

5.3. Block level

Scaling up from plot level is the block level. A block is a plot (garden and building) being multiplied and enclosed by streets. There are multiple ways an urban planner can design a block. The design of a block can have an effect on the biodiversity levels in green urban areas. In Figure 12, six possible designs of blocks in the residential area are shown. The possible designs are:

1) Building surrounded by public green
2) Classical block that enclosures a shared green area
3) Detached houses surrounded by private gardens
4) Houses with front and back gardens that enclose a shared area (green or not)
5) Classical block with front and back private gardens
6) Houses with private back gardens

Unfortunately, no research has been performed yet on the configuration of green areas on block level. However, it is hypothesized that the configuration of private gardens or collective green can have an influence on the biodiversity levels of the flora and fauna in the urban area.

Figure 12; Possible design options for block configuration. 1) Building surrounded by public green, 2) Classical block that enclosures a shared green area, 3) Detached houses surrounded by private gardens, 4) Houses with front and back gardens that enclose a shared area (green or not), 5) Classical block with front and back private garden, 6) Houses with private back gardens

5.3.1. Private gardens (on block level)

Unfortunately, no research has been performed on the effect of the configuration of green private spaces in blocks on the biodiversity levels of different species groups. Up till now, the scarce but growing, amount of research on garden biodiversity did now mostly focused on individual gardens. An important next step would be to treat the gardens not as independent ecosystems, but instead as an interconnected habitat within the urban ecosystem. This could provide important information for urban planners and (landscape) architects to efficiently incorporate green areas to increase biodiversity. Research that still needs to be performed include questions such as: What is the optimal private garden patch size (for different taxa)? And what is the optimal configuration of private gardens (for different taxa)? For example, should one big green area be created inside a block or should gardens be placed on the outer sides of the houses of a block in order to reach the highest wildlife diversity?

Since no research has been performed in this field, only hypotheses can be formulated. Every houseowner or garden owner has their own preference in what flora to use in their private gardens. Therefore, all gardens in a block have a different plant species composition. This suggests that on block level a higher biodiversity of plant species could be found compared to the plant biodiversity levels on plot level. This biodiversity of plant species could also possibly affect on the wildlife composition on the block level.

A useful way to improve the success and survival of wildlife is by meeting the species life-cycle requirements. For the biodiversity and survival of species it is important to focus on each phase in its life-cycle, from birth to reproduction to death. Examples of critical requirements are food sources, nesting sites or protection from predators. For (landscape) architects, this needs to be a main focus point as well. For example, if nesting stones are incorporated into the design of a building, food sources also need to be available for the animals, otherwise it is hypothesized that the nesting stones will not be used sufficiently. This is a relatively new concept called "Animal-Aided Design", which is a methodology for the design of urban spaces with the idea to include the presence and the life cycle of wildlife into the planning and design process (Weisser and Hauck, 2017). For some species (e.g., small invertebrates such as snails) it is possible to complete their entire life cycle within a single garden. On the contrary, for many of wildlife species a single garden may only contribute to a part of their life-cycle, because they only provide a part of their needed resources (Braschler et al., 2020). If life-cycle requirements are included in the NIUD of a block, the success and survival rate of wildlife would most likely improve in comparison to when this is not incorporated.

Many wildlife-species are forced to modify their special distribution to meet their life-cycle requirement in fragmented urban areas (Ditchkoff et al., 2006). By connecting private gardens, the area covered by vegetation can be enlarged and habitat fragmentation can be decreased and life-cycle requirements can be met easier. In ecology, the species-area curve concept predicts that the number of species increases proportionally with the area increase at local level (Rice and Kelting, 1955) (Figure 13). Figure 13 shows that species richness increases with an increase of area and, therefore, it is expected that by enlarging the green area it has a positive effect on wildlife-abundance and diversity.

Besides, gardens can improve connectivity by functioning as corridors or by enlarging the size of other urban habitats (Goddard et al., 2010). An expected greater resource availability (more flowering plants), due to a better connectivity, will attract more pollinators to visit private gardens (Salisbury et al., 2015). With a bigger garden size and area covered by vegetation, a higher bird species richness (Chamberlain et al., 2004; Thompson et al., 1993; van Heezik et al., 2013) and a higher garden use of mammals is expected (Baker and Harris, 2007). Besides, as mentioned before, invertebrate abundance and species richness is mostly explained by plant structural heterogeneity and taxonomic diversity (Richard M. Smith et al., 2006b, 2006a). By connecting gardens, it is expected that structural plant structural heterogeneity and taxonomic diversity will be increased and thus increase invertebrate abundance and diversity.

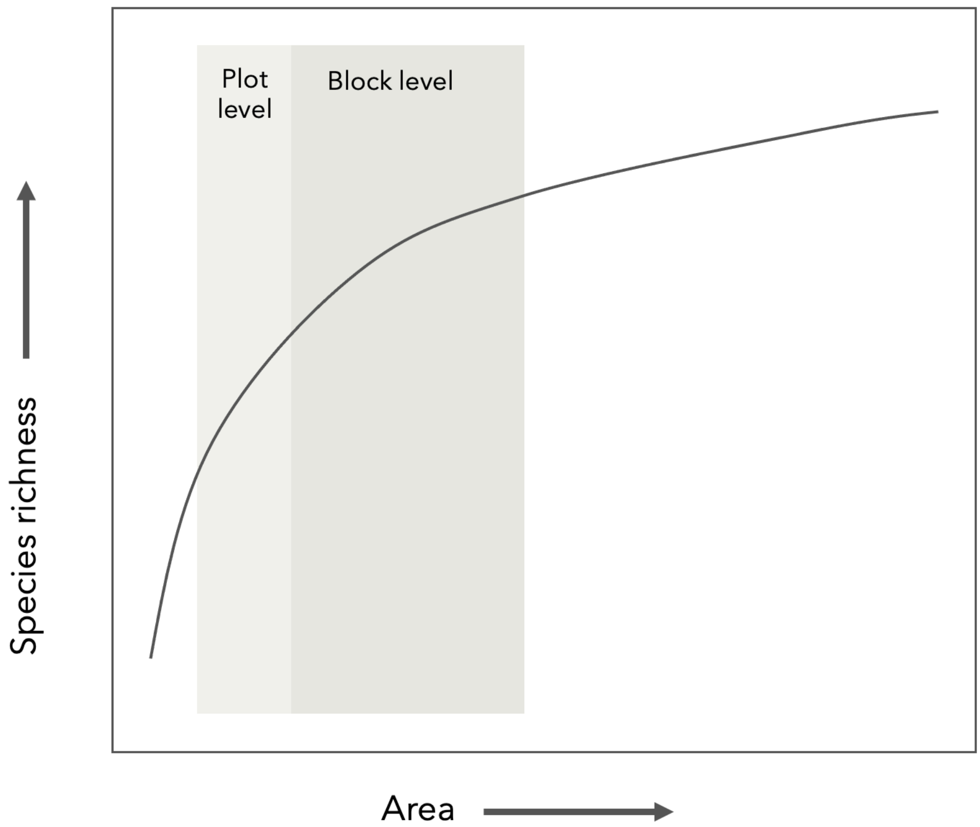

Figure 13; Concept of the species-area relationship (based on the Rice and Kelting (1955) species-area curve concept). This figure shows that species richness increases with an increase of area. Plot and block level are indicated to show the concept that on block level a higher species richness can be found compared to the species richness on plot level.

5.3.2. *Collective green*

Other greenery that is used on block level are the shared green spaces, which is often owned by a housing corporation. Usually these housing corporations hire a professional to manage this type of green space. This type of green space can benefit urban biodiversity since the space that is created for urban green is usually larger than a private garden. Within this area there is more space for different biotopes, such as ponds or large trees. Usually the area of a private garden in the residential area of a city is too small to offer such elements and biotopes. Therefore, it is hypothesized that a shared green space can offer different habitats and therefore a different biodiversity than in private gardens, or when private gardens are connected. Besides, an urban planner can give the housing corporation directions on how to design the area to create a biodiverse green space. For example, the urban planner can take into account that all parts of the life-cycle of species(groups) need to be incorporated in the design. Life cycle requirements that can be taken into account are foraging and nesting but also shelter opportunities.

Other shared green spaces are "common gardens", which are green spaces in the urban area that depend on collective management. Individual urban dwellers or communities can participate in the management of the green space where they hold some rights, including access right, withdrawal right, management right and sometimes exclusion rights (Colding and Barthel, 2013). Since all common gardens are designed in a specific way, it is hard to make conclusions about biodiversity levels on species groups. However, Dennis and James (2016b) determined the links between biodiversity potential, site access and user participation, where biodiversity potential was assessed using floristic and structural diversity as a surrogate. They showed that biodiversity measures were both influenced by community-led ecological participation and site accessibility. Higher community-led participation (hours of voluntary work per month) was associated with higher biodiversity. The amount of voluntary input in common green spaces was found to be influenced by the accessibility of the site. Sites with free public access were found to have lower levels of voluntarism than sites that were private or that had limited access (Dennis and James, 2016a). Therefore, highest biodiversity levels are expected at shared gardens with limited or private access.

Next to potential biodiversity benefits, there are several benefits that could be associated with collective green. Firstly, collective green can reduce management costs by the shared governance (Colding et al., 2013). In additions, public or common gardens or other managed green areas also have an important role in reducing the "extinction of experience". These natural environments in the urban area can bridge the disconnection that exist between humans and the environment, and therefore decrease the 'extinction of experience' in cities (Colding et al., 2013; Miller, 2005) and enhance the emotional attachment to nature and increase the motivation to visit nature in the future (Bixler et al., 2002; Soga and Gaston, 2016). Moreover, collectively managed green spaces appear to have multiple benefits on human well-being, community cohesion and crime reduction (Dennis and James, 2016b).

5.4. Street level

In the next sections, different measures of NIUD that can be applied on street level will be discussed. Measures that will be discussed are “street trees” and “wildlife-crossing structures”.

5.4.1. Street trees

The role of trees in the street has changed over the last 30 years from one of beautification and ornamentation (aesthetic role) to one that also includes environmental service provision (Silvera Seamans, 2013). Street trees have numerous environmental and health benefits.

First of all, street trees can enhance biodiversity by providing food, habitat and landscape for urban fauna (Mullaney et al., 2015). The diversity and the abundance of the wildlife can be influenced by the type and height of the tree. Therefore, it is recommended to plant a diversity of (native) tree species to prevent homogenization of the urban fauna (Alvey, 2006).

Urban streets have the potential to support diverse bird communities. Planting trees is an ideal way to provide birds with food, shelter and nesting spots. An advantage of using trees in streets is that they can act as a corridor for bird species, and thus provide movement of bird species throughout the city (Fernández-Juricic, 2000). Increasing street tree richness can increase urban bird species richness (Pena et al., 2017). The size and the age also have an effect on the bird community. Larger trees increase the complexity of the canopy and can provide critical resources (e.g., fruit and seed production, flowers and provision of nesting opportunities in cavities) (Pena et al., 2017). Previous research has shown that areas with large trees can increase urban bird species abundance and richness (Pena et al., 2017). Streets that mainly contain native tree species, instead of exotic tree species, can increase (native) bird species richness, induce a higher functional richness and the bird community composition will be more similar to the community composition in the natural habitat compared to streetscapes (Pena et al., 2017; White et al., 2005). The use of native trees in an urban street can benefit native birds by providing a habitat that is more suitable for native species over exotic species (White et al., 2005). Another advantage of trees in urban areas is that they reduce the negative effects of the exposure to noise on the bird community (Pena et al., 2017).

The use of trees in urban streets can contribute to the conservation of arthropod diversity (Bhullar and Majer, 2000). Data about the abundance and diversity of arthropods is limited. However, Racelis *et al*. (2013) investigated the arthropod abundance and diversity in street trees of south Texas (USA), which showed that arthropod abundance was higher on street trees that are native to the study area, compared to non-native trees. The abundance and diversity of arthropods on trees is a reflection of the geological history of the trees. The more recent the arrival of the trees, the less arthropods are likely to use the tree as their habitat (Bhullar and Majer, 2000). These results add to the growing evidence that urban areas that maintain native vegetation can preserve a higher biodiversity (Perre et al., 2011; Racelis et al., 2013). Recently, investigators examined the risk of bird predation and abundance of leaf-eating insect abundances in urban forest fragments and street trees (Long and Frank, 2020). They expected that insects might flourish better in street trees, where the risk of bird predation is lower than in urban forests. However, the results showed that the insect abundances were higher in urban forests compared to street trees, even if they have to tolerate a higher level of predation. This is likely due to street trees having less vegetational complexity and diversity, and thus having less insectivorous birds and mating opportunities (Long and Frank, 2020). Furthermore, arthropod density and diversity differs greatly between tree species within an ecosystem. However, research on the abundance and diversity of arthropods on European street trees has yet to be conducted.

Planted street trees might offer important floral resources to pollinating insects (Somme et al., 2016). Somme *et al.* (2016) investigated the suitability of urban trees as resources for pollinating insects by examining the nutritional quality of the pollen and nectar (the amount of nectar produced and chemical composition of pollen and nectar) of nine major insect pollinated tree species in Western Europe. The tree species that are included in this study are *Acer pseudoplatanus, Aesculus carnea, A. hippocastanum, Robinia pseudoacacia, Tilia cordata, T. x euchlora, T. x europaea, T. platyphyllos* and *T. tomentosa.* The results showed that the nine investigated urban tree species could be important protein resources for pollinating insects and that the urban tree flowers contained relatively high sugar content, although sugar content varied greatly within genera. Moreover, planting a variety of native and exotic tree species could provide a higher diversity of the floral resources and provide more pollinator species to find suitable resources. (Somme et al., 2016).

Street trees can provide connectivity between green spaces in urban areas. Therefore, street trees can act as corridors for small mammals (Mullaney et al., 2015). Trees are also important habitats for bats (Kalcounis-Rüppell et al., 2005), especially in urban areas where roosting opportunities can be limited for tree-dwelling bats (Straka et al., 2019). Next to providing roosting opportunities for bats, trees also minimize the negative effects of artificial lights on bats, where dense tree cover were found to minimize the negative effects of street lamps for open space foraging bats (Straka et al., 2019).. Similarly to birds, native tree species are widely used by bats and especially large trees are preferred that are close to large numbers of preferred food trees (Mullaney et al., 2015).

Street trees can incept large volumes of rainwater, which can significantly reduce peak volumes of rainwater and reduce the amount of costly-stormwater infrastructure (Mullaney et al., 2015). Besides, trees can reduce energy consumption when placed close to building by effecting and providing shade and evotranspiration (Groth et al., 2016). Moreover, the presence of trees in the streets has multiple benefits for the health and the well-being of urban dwellers. Trees can improve the air quality by capturing airborne pollutants (such as ozone, nitrogen oxides, sulphur oxides, Sulphur dioxides, carbon monoxide, carbon dioxide) (Tallis et al., 2011). Furthermore, Kardan *et al.* (2015) investigated the relationship the presence of trees and the perceived health using street tree data, satellite information and results from a province wide survey from the Ontario Health Study. Their results suggest that people who live in a neighborhood with higher tree densities in their streets (more than 10 trees per neighborhood block) reported higher health perception. Next to having positive consequences on the human health and general well-being, more trees are also associated with a better connection of urban dwellers with nature. A study by Nisbet *et al.* (2020) showed that a more dense tree canopy in a neighborhood is related to a higher connectedness of people to the neighborhood, their neighbors, the trees, the wildlife and to nature in general. However, it could also be possible that people who are already more connected to nature seek out to a neighborhood with more trees instead of trees enhancing the connectedness.

It should be noted that a lot of the benefits are not fully realized, because tree growth if often limited by design issues that affect the access to water, air and nutrients (Mullaney et al., 2015). Therefore, in the design of streets, these limiting factors should be considered and minimized. Besides, especially when streets with trees are designed within canyons, careful management of the crown is recommended to promote air flow and the uptake of harmful pollutants. Small trees with few leaves are less effective in the uptake of harmful pollutants and particulate matter, whereas large trees with large crown diameters can obstruct the upward air flow and dispersion of air. If the air exchange is hindered, the concentration of pollutants rises in the pedestrian level, therefore adequate space between tree crowns and nearby buildings is recommended (Gromke and Ruck, 2007). Next to this, street trees can cause disruptive and costly damage to pavement infrastructure (Coder, 1998). In the design of streets this should be considered by using appropriate materials and installation procedures.

5.4.2. Wildlife-crossing structures

Figure 14; Tree canopy bridge for squirrels and martens

Streets, or other linear infrastructures can act as both physical and biological barriers to many wildlife species. They can cause a fragmentation in the habitat of the flora and fauna in urban area (Glista et al., 2009). This causes less possibilities for plants and animals to disperse between areas. A variety of mitigation approaches are used to reduce the negative effects (such as connectivity and wildlife-vehicle collisions) of roads or other linear infrastructure. Wildlife-crossing structures can ensure that the different habitats remain or become connected to each other. This connectivity between populations on both sides of the road allow animals to access resources and possible mates and therefore facilitate gene flow which increases the viability of wildlife populations in urban areas (Smith et al., 2015). There are two main categories of wildlife-crossing structures: underpasses (e.g., wildlife-tunnels, ecoducts) and overpasses (e.g., tree canopy bridges, viaducts). However, there is a large variation in these two main categories in their sizes, shapes, materials, target species and construction style (Smith et al., 2015). These structures should enable a safe passage for animals, promote the connectivity between habitats and encourage natural movements (Glista et al., 2009).

The role of roads as barriers and how this affects the movement of wildlife in urban areas, together with possible mitigation strategies, has recently received considerable attention.

However, there is still much to learn about their effectiveness at contributing to the conservation of biodiversity (Smith et al., 2015). A literature review by Van der Ree *et al*. (2007) evaluated the scientific rigor and methodology of studies to mitigation strategies. This review showed that of the 123 studies that were reviewed, only two studies demonstrated a positive effect on population level. The other 121 studies found an effect on the individual level. This shows that more research is needed on population level to draw better conclusions about the connectivity and movement between habitats and how this affects wildlife populations in urban areas. Besides, more research needs to be performed to show if the negative effects of roads have been mitigated sufficiently by mitigation strategies so that the long-term survival of urban wild-life is enhanced enough.

An example that can be used in the residential sub-urban area of a wildlife crossing structure is a tree canopy bridge (Figure 14). A tree canopy bridge can be used to connect habitats for animals that live in trees when the road is too wide to allow a connection between trees on either sides of the road. The main target species for this type of corridor is the squirrel. However, depending on the type of the tree bridge, other mammals (e.g., martens or mice) might use the tree bridge (Vercauteren et al., 2015). Although there is increasing interesting in the use of tree bridges, experiences with them remain scarce. Examples of squirrel bridges can be found in Den Haag (the Netherlands), Jersey (UK), Wight (UK), Germany, France and Japan (Vercauteren et al., 2015). A study by Mulder (2012) investigated the use of a tree bridge in Zeist (the Netherlands) (Mulder, 2012). They proved that the bridge was used, however in a very small extend and only by squirrels. However, these results might be influenced by the fact that this was a new bridge and animals need to adapt to the bridge before they might use it. Other factors that can influence the efficiency of tree bridges are the type of bridge, the location and the target species (some species are adapted faster than other species) (Vercauteren et al., 2015). The scarce empirical research that is performed on tree bridges mostly focused on the monitoring of the use of the bridges. However, it would be useful to investigate the efficiency on population level and if migration or population size could be benefitted by the use of tree bridges.

5.5. Neighborhood level

On neighborhood level urban planners need to design a floorplan on how to disperse the buildings, blocks and streets in the area. Different measures to include nature in the design of a neighborhood are the separation of "soft" and "hard" landscapes and connecting the neighborhood with the surrounding area with the use of wildlife corridors.

5.5.1. Keeping soft- and hard landscape functions apart

With the perspective of an urban developer, there are two main elements that can be included in the (residential development) design and these are referred to as "soft" and "hard" landscapes. Soft landscapes are the landscapes with the vegetative material and including all types of plant life and the water zones, where activities such as walking and cycling can occur. Contrary, hard landscapes consist of the inanimate elements of the landscape, consisting of the pacing, roads for motorized traffic, housing, car parking, fences and so on. Urban wildlife could possibly be supported by separating the "soft" landscapes from the "hard" landscapes, since stressors such as light pollution, noise pollution or human disturbances will be lower than normal in the "soft" landscapes, which could be beneficial for the wildlife in those landscapes.

Artificial light pollution (ALP) is described as any artificial light that changes the natural patterns of dark and light in ecosystems (Longcore and Rich, 2004; Newport et al., 2014). The two main key sources of artificial lights in urban areas are 1) street, house and public lighting and 2) floodlights, usually from sport grounds and from industrial areas. (Newport et al., 2014). In the residential area of a city the street, house and public light source is the main source of light pollution. This type of artificial light is usually on all night, which gives a mix of varying but constant intensities of illumination. ALP can have consequences on urban wildlife and its biodiversity. Foraging, reproduction, communication and other critical behaviors can be affected by ALP, since APL can cause an (dis)orientation experience in animals (Longcore and Rich, 2004). Moreover, interspecific interactions, that are evolved in the natural patterns light and dark, can be affected and disrupted by artificial light. This can have implications for community ecology (Longcore and Rich, 2004). Artificial light can also increase travel time and stress of urban wildlife, and therefore have effects on their spatial behavior and movement (Newport et al., 2014). Next to light pollution, noise pollution (any human made sound) can alter the behavior of animals and can interfere with their functioning. Reproduction, communication, habitat use and distribution are examples of behavior of animals that can be altered by noise pollution (Newport et al., 2014). Overall, noise level increase can cause a decrease in species abundance and richness in an area (Newport et al., 2014). Concluding, both noise and light pollution can have an effect on the abundance and spatial behavior of urban wildlife.

The effects of ongoing human disturbance to wildlife in habitat remnants is a major conservation concern. In this context, a disturbance denotes a deviation in the animal's behavior from their natural behavior without human influenced. Human induced disturbances can be related to different stimuli (e.g., sound, vehicles, birdwatchers, etc.). Animal behavior can be dramatically affected by human disturbances (Markovchick-Nicholls et al., 2008). Human disturbances can be perceived similarly to predation risk, where similar trade-offs between the avoidance of the perceived risk and fitness-enhancing activities (e.g., mating, feeding or parental care) are found (Frid and Dill, 2002). By providing a more distinct and separate area for nature, human disturbances can possibly be mitigated. Previous research has shown that the presence of dogs and people had a negative effect on bird species richness and abundance (Fernández-Juricic and Tellería, 2000; Paker et al., 2014). Moreover, human disturbances can cause birds to spend more time being vigilant and moving away from people and less time on foraging behavior (Fernández-Juricic and Tellería, 2000). By minimizing human disturbances, this could possibly positively affect the bird species richness and presence. These responses, found in bird species, could also affect densities of other urban species. Sensitivity to human species might differ among species, however, in general larger species are more sensitive to human disturbances (Cooke, 1980; Fernández-Juricic and Tellería, 2000).

5.5.2. Wildlife corridors

For the connection of an area with the surrounding space it is important to allow for floral and faunal movement through the new area. For this to happen it is important to create corridors and minimize disturbing stresses (e.g., light pollution).

First of all, to allow migration it is important to create corridors from the surrounding area to and through the neighborhood. Next to the use of wildlife-crossing structures, the use of green wildlife corridors is important for the dispersal of urban flora and fauna. Wildlife corridors are features linking habitat patches that were once connected or need to be connected to allow wildlife to migrate through the landscape (Evans, 2007). A well designed corridor in not only a habitat on itself, but it is part of a network since it can form links between habitats (Gemeente Amsterdam, 2020). It is supposed that a network of corridors can provide and maintain higher levels of biodiversity than a landscape with no corridors linking the fragmented landscape (Evans, 2007).

As mentioned before, street trees are important habitats for bats and birds, which can act as corridors. Street trees can connect the surrounding vegetation with green areas in cities and provide corridors for the dispersal of birds, bats, small mammals and other fauna such as butterflies, moths and beetles (Mullaney et al., 2015). Next to trees that can act as corridors another possible solution are green hedges, a habitat for birds, insects and small mammals (Atkins, 2019; Atkins et al., 2018; Gemeente Amsterdam, 2020). Relatively little is known about the biodiversity value of hedges in urban areas (Atkins, 2019). Nevertheless, previous research has shown that hedge preference differs between species (Atkins, 2019). Therefore, in this type of corridor it is recommended to use a combination of different plant species, to attract a higher fauna diversity (Gemeente Amsterdam, 2020). Another type of corridor that is receiving more and more attention are the so-called butterfly- and bee 'idylles', flower-rich greenspaces, since the abundance and species richness of these species are decreasing in urban areas (Clark et al., 2007; El Ghomari, 2019) These idylles are verges, patches, strips or fields with herbs, flowers and plants that can be beneficial for (pollinating)insects (e.g., butterflies and bees). However, there is still a major knowledge gap regarding the potential of verges alongside linear transportation structures as corridors for insects. Thus, more research on this topic is encouraged (Villemey et al., 2018). Although these types of corridors are designed for (pollinating) insects, other urban wildlife (e.g., small mammals such as mice) can also make use of these green corridors (Galantinho et al., 2020). Another example, which is a new measure for wildlife corridors, is a so called “wilderness wall” (Gemeente Amsterdam, 2020). This is a wall with holes and crevices which forms different microclimates and can act as shelter or foraging grounds for small organisms (Gemeente Amsterdam, 2020). Nonetheless, no scientific research regarding this type of corridor has been found. Lastly, a wildlife corridor can be designed, possibly with the configuration of gardens. However, as mentioned before no research has been performed on the configuration of gardens.

To allow urban wildlife to migrate through a neighborhood, corridors are very important, but it is also important to minimize stress in order to maximize the use of the corridors. Two important stressors that needs to be avoided are light and noise pollution. This needs to be taken into account if the neighborhood wants to be connected to the surrounding area and the movement of wildlife through the area needs to be supported. In the design of a wildlife corridor, it is therefore recommended to minimize light and noise pollution by for example only allowing light that is needed for safety. Another option is to keep the “soft” landscapes separated from the “hard” landscapes as discussed previously.

5.6. Remarks on the evidence of nature-inclusive urban development measures

As described in the previous sections, several measures can be used to include nature in the urban development on different levels. In general, the literature showed that positive effects on biodiversity levels for wild flora, birds, (pollinating)insects and mammals are found for all measures. In tables 2 and 3 the key findings about the different measures that are covered in this report are summarized.

The availability of scientific evidence about the different measures and species groups differed greatly. Table 1 shows a summary of the availability of scientific evidence of the measure, based on what is found in the scientific literature and my personal impression of the availability. Most of the research that is performed on the measures on building level is evidence based, especially for green roofs. However, literature is scarce for measures on higher levels. To draw more conclusion on how nature-inclusive urban development measures can contribute to biodiversity levels in urban areas, more research needs to be performed, especially on higher levels. Besides, most studies performed on the measures was performed on birds. For other species groups such as (pollinating) insects and mammals, scientific evidence on these measures is still scarce.

Table 1; Availability of scientific evidence.
+ = multiple scientific studies are found, +/- = scientific publications are scarce, - = little to no scientific studies are found, n/a= not applicable.

Level	Measure	Birds	Insects	Pollinators	Mammals	Wildlife general
Building	Green roof	+	+	+	+	+
	Green wall	+	+	+/-	-	+/-
	Nesting box - birds	+/-	n/a	n/a	n/a	n/a
	Nesting box - bats	n/a	n/a	n/a	+/-	n/a
	Nesting box – pollinators	n/a	n/a	+/-	n/a	n/a
Plot	Private gardens	+/-	-	-	-	+/-
Block	Private gardens	-	-	-	-	-
	Collective green	-	-	-	-	-
Street	Street trees	+	+/-	+/-	Small mammals +/- bats +	+/-
	Wildlife crossing structures – tree canopy bridges	n/a	n/a	n/a	+/-	n/a
Neighborhood	Separating hard/soft landscapes *	+				+
	Wildlife corridors *					+/-

* Information about species groups is highly dependent on what type of wildlife corridor or measure for separation the "soft" and "hard" landscape is used. Therefore, no statements can be made about the biodiversity levels of the different species groups on the measures on neighborhood level.

Table 2; Key findings on building and plot level

Level	Measure	Biodiversity (general)	Birds	Insects	Pollinators	Mammals
Building	Green roof	Can provide undisturbed and/or new habitat and thus enhance biodiversity.	Main reason to visit is for foraging and can sometimes provide nesting opportunities.	Can restore habitat. However, slightly greater insect diversity on ground-level habitats.	Can be a foraging and nesting habitat, dependent on (blooming) plant diversity and abundance.	Can provide foraging opportunities for bats, especially on biodiverse roofs
	Green wall	Can have greater potential than green roofs considering the surface area of green walls.	Can provide nesting, foraging and shelter opportunities (especially in winter). Bird activity is higher compared to bare walls.	Higher diversity compared to bare walls. Good disperses (e.g., winged insects) are over represented.	Can provide food resources. Pollinator abundance depends on number of floral species.	
	Nesting box – birds		Provides nesting opportunities. Effect is positive in many cases, but use varies between species.			
	Nesting box - bats					Can provide nesting and shelter opportunities. Generalist species are more likely to roost in boxes than species with specific requirements.
	Nesting box – bees				Can provide nesting opportunities, but more research is needed on usefulness.	
Plot	Private garden	Can act as stepping stones in ecological network	Bird species richness is positively correlated with native plant biomass, and affected by tree and shrub cover. Cover in gardens can provide nesting, foraging, and shelter opportunities.	Abundance is mostly explained by plant structural heterogeneity and taxonomic diversity	Floral species can provide food resources and enhance pollinator abundance. A variety of flowering plants with a higher abundance of native and near-native plants and some exotic flowering plants are recommended.	Can provide nesting, shelter and food resources. Availability in influenced by behavioral, environmental factors (e.g., vegetation structure and diversity), additional feeding and age of city development.

Table 3; Key findings on block, street and neighborhood level

Level	Measure	Biodiversity (general)	Birds	Insects	Pollinators	Mammals
Block	Private garden	By connecting gardens, biodiversity can be increased since number of species increases by area increase and life-cycle requirements can be dispersed over multiple gardens.	By connecting gardens, garden size and vegetation cover can be increased which can increase bird species richness.	By connecting gardens, plant structural heterogeneity and taxonomic diversity can be increased and thus it is expected that this will increase invertebrate abundance and diversity.	More pollinators will visit gardens with a greater resource availability (more flowering plants).	Larger garden size (by connecting gardens) can increase higher garden use by mammals
	Collective green	Can offer more space for different biotopes and can therefore provide different habitats for urban wildlife. Highest biodiversity levels are expected at shared gardens with limited or private access.				
Street	Street trees	Can provide food, habitat and landscape for urban fauna.	Can provide foraging, shelter and nesting opportunities. Especially native tree species can increase bird species richness. Street trees can act as a corridor for birds.	Higher abundances are found on native species compared to exotic species.	Can offer important floral resources. Planting a mix of native and exotic tree species could provide a higher diversity of floral resources and thus a higher diversity of pollinating insects.	Can act as corridors for small mammals. Can act as roosting habitat for bats and minimize light pollution.
	Wildlife crossing structures – tree canopy bridge	Can connect different areas and thus allow for the migration of urban wildlife				Can connect habitats. More research is needed on usefulness and efficiency on population level.
Neighborhood	Separating soft- and hard landscapes	By separating the "soft" and "hard" landscapes the negative effects of stressors such as light pollution, noise pollution or human disturbances could be reduced	Minimizing human disturbances could positively affect the bird species richness and presence			
	Wildlife corridors	A network of corridors can provide and maintain higher levels of biodiversity than a landscape with no corridors linking the fragmented landscape				

6. Evaluation of the effectiveness of NIUD scenarios

With the ongoing urbanization, both worldwide and in the Netherlands, cities are expanding and getting more compact. Especially in Northern America, Latin America, the Caribbean and Europe, cities are expanding rapidly (see chapter 2.1). Also, in the Netherlands a significant population growth is expected in the four major cities (Amsterdam, Rotterdam, Den Haag and Utrecht). This urbanization has consequences on the biodiversity in urban areas and it is one of the major causes of species extinction (Czech et al., 2000; McKinney, 2006). One solution to bring nature to cities is by nature-inclusive urban development. In chapter 3, three scenarios to include nature in the urban development are formulated. In this chapter, the effectiveness of these scenarios based on the evidence of the different NIUD measures as described in chapter 5 are evaluated. The effectiveness of the different scenarios is tested by evaluating the conservation of species (i.e., what are the target species-groups and what life-cycle requirements can they fulfill) and the what the different scenarios can bring for the nature experience of the urban dwellers.

6.1. Scenario 1: Effectiveness of including nature in direct living environment

The first scenario focusses on the direct living environment of the urban dweller (Figure 15). The measures to accomplish this scenario should therefore focus on the individual building and plot level, since these levels are in the urban dweller's direct living environment. Measures that could be included are "green roofs", "green walls", "nesting boxes" and "private gardens".

Figure 15; Scenario 1: Including nature in the direct living environment

Measures provided on building and block level could potentially increase and support urban wildlife in the direct living environment of the urban dweller. By providing these measures, residents can experience nature directly in their living environment. This form of nature will be the first type of green in the direct living environment of the urban dwellers and will be often be the first experience of nature for children. Nature can be both experienced by the view of nature from inside their homes, but also by enabling urban dwellers to physically experience and touch nature. This will decrease the 'extinction of experience'. The ongoing loss of human interaction and the 'extinction of experience' is a major concern regarding future biodiversity conservation and global environmental challenges. People who experience nature frequently have a greater affinity to support and protect biodiversity (Soga et al., 2016; Soga and Gaston, 2016). Therefore, in order to protect biodiversity people should be encouraged to experience nature and be provided with various types of nature experience. Bringing nature into the direct living environment can offer such experiences.

Although the measures provided on building and block level could increase and support urban wildlife in the direct living environment, the effect of the measures on biodiversity levels can be affected by the number of households that are interested in including nature design of the direct living environment. The literature showed that the measures on block and plot level often only provide a small part of the life-cycle requirements needed by fauna. For some species (e.g., small invertebrates) it is possible to support their entire life-cycle within a small area, like a single garden or green roof, but other species, such as ground dwelling mammals, often require more area and resources to fulfill their entire life-cycle. For example, green walls mainly provide foraging opportunities for birds and bats (Fernandez-Canero and Gonzalez-Redondo, 2010; Pearce and Walters, 2012), nesting boxes can provide nesting opportunities and green walls can offer food resources for pollinating insects (Mayrand et al., 2018). Next to animals that can fulfill their entire life cycle within a small area, another group of species that can benefit from this scenario are the highly vagile animals. Highly vagile animals are good dispersers and can therefore find other life-cycle requirements in different places or other blocks. Therefore, a disadvantage of this scenario is that it will mainly support organisms for which a small area (e.g., a private garden) meets their entire life-cycle requirement in this small area and highly vagile animals (e.g., many species of birds, bats, and large insects).

This disadvantage will be less present if more households have the desire to include nature in the direct living environment, since the area of greenery would then increase and could thus possibly provide more life-cycle requirements. It could be so that in a neighborhood only a small number of households have the desire to include nature in their direct living environment. The project developer can then provide measures to support these desires, such as nesting stones, green roofs, or green walls. However, if only one household in a block has a green roof and all the other neighbors do not have greenery to support urban wildlife, than it is possible that this one green roof does not have enough area a high variety of urban wildlife, since number of species increases proportionally with the increase of green area at local level (Rice and Kelting, 1955). Besides, as mentioned before by providing only one household with measures for including nature in the direct living environment the life-cycle requirements will highly likely not be met for most urban wildlife. If more households are interested in including nature in the direct living environment, the life cycle requirements can be dispersed over multiple households. To attract more diverse urban wildlife to the direct living environment and to overcome this disadvantage, it is necessary for the urban developer to take this into account. If a greater variety of urban wildlife is desired, the urban planner should provide other greenery on higher levels (e.g., verges, street trees, etc.) in the surrounding area that could support other stages of the life-cycle.

6.2. Scenario 2: Effectiveness of creating a biodiverse habitat on community level

The second scenario focusses on the community level in the residential area. Therefore, measures that can be used to accomplish this scenario should focus on the block level. On block level “private gardens” or “collective green” could be used as measures to accomplish this scenario.

Similarly to scenario 1, residents can experience nature directly in their living environment, from inside their homes or by physically experience and touch nature. This can decrease the ‘extinction of experience’.

Figure 16; Shared gardens "Kersentuin" in Leidsche Rijn

To support a diverse species composition on block level, a possible solution would be to connect private gardens to increase the possible habitat area. Since the species-area curve concept predicts that the number of species increases proportionally with the area increase at local level (Rice and Kelting, 1955), connecting private gardens could potentially increase species diversity on block level. Besides, gardens can improve the connectivity by functioning as corridors or by enlarging the size of other urban habitats (Goddard et al., 2010). By connecting gardens connecting gardens it is expected that habitat fragmentation is decreased and species diversity can be increased. It should be noted that connectivity between gardens can especially be important for non-flying animals and for gardens enclosed by physical barriers (e.g., fences or buildings), since they can alter or block the movement of non-flying animals between gardens and between gardens and the surrounding area (Bergey, 2019). Movement can be promoted by replacing solid fences by, for example, hedges which also provides nesting opportunities.

Moreover, due to the limited life-cycle requirements provided by single gardens, many wildlife species are forced to modify their spatial distribution to meet their life-cycle requirements in fragmented urban areas (Ditchkoff et al., 2006). By connecting private gardens more life-cycle requirements are available in a less fragmented habitat. Herein also lie possibilities for the urban developer, who can consciously disperse the different life-cycle requirements over multiple gardens within a block.

Another example to support a high species diversity on community level is by shared green spaces. An example of a shared green space is the “Kersentuin” in Leidsche Rijn (Utrecht, the Netherlands). The inhabitants of this community wanted a green, sustainable and social living environment. In the design of the community, the inhabitants, municipality, architect and contractor worked together to accomplish this goal. A decision they made was to remove private gardens from the design plan and exchange them for a shared garden. By doing this the community created a biodiverse garden (Figure 16). However, shared gardens are still very rare green spaces, but have a great opportunity in providing a diverse urban wildlife. The disadvantage of this type of green space is that it requires participation of the urban dwellers to make it a success, since biodiversity is influenced by community-led ecological participation (Dennis and

James, 2016b). Moreover, participation in common green spaces is found to be influenced by the accessibility of the site. Sites with free public access were found to have lower levels of voluntarism than sites that were private or that had limited access (Dennis and James, 2016a). Therefore, highest biodiversity levels are expected at shared gardens when access is limited or private. In short, these types of urban green, connected private and shared gardens, can possibly support a higher biodiversity than without a connection (scenario 1). However, more participation from urban dwellers is needed to make this scenario a success for biodiversity conservation.

6.3. Scenario 3: Effectiveness of creating a built environment that is part of the surrounding area

The third and last scenario focusses on creating a built environment that is part of the surrounding area (Figure 17). This is often a demand of a municipality that the urban developer needs to take into account. With this scenario a connection between the surrounding area and the built environment can be made. The measures to accomplish this scenario should focus on neighborhood level. Measures that can be used are "wildlife corridors" (e.g., street trees, fauna passages or 'idylles') and separating the "soft" and "hard" landscapes to support migration of urban wildlife. With the use of these scenarios a green zone will be provided in and through a neighborhood.

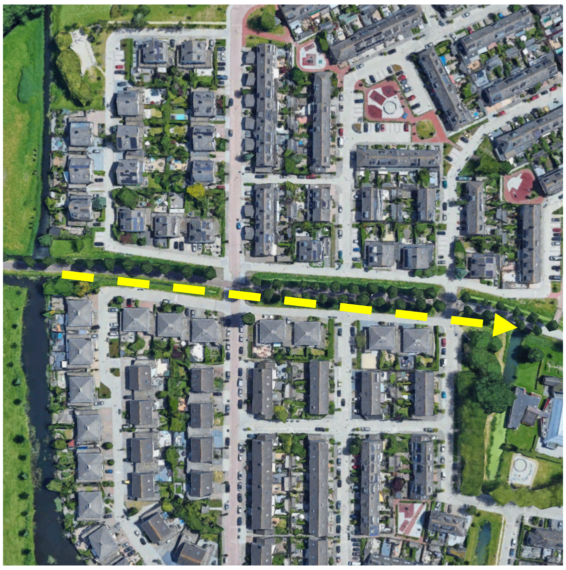

Figure 17; Scenario 3: Creating a built environment that is part of the surrounding area

An important reason to create a built environment that is part of the surrounding area is to promote the movement of nature and urban wildlife though the area. It is supposed that a network of corridors that link fragmented landscapes can provide and maintain higher levels of biodiversity than a landscape without corridors (Evans, 2007). Therefore, with the use of wildlife corridors, green areas such as parks can be connected, which promotes movement through a neighborhood and which can lead to higher levels of biodiversity than are expected in neighborhoods without the measures. Besides, a wildlife corridor can be used to separate of "soft" and "hard" infrastructure. By doing so, stressors such as light pollution, noise pollution and human disturbances, which have a negative impact on urban wildlife (Fernández-Juricic and Tellería, 2000; Frid and Dill, 2002; Markovchick-Nicholls et al., 2008; Newport et al., 2014; Paker et al., 2014) can be minimize and settlement and movement of urban wildlife in the neighborhood will be promoted. Consequently, a wildlife corridor in the residential district can increase the opportunity that extraordinary wildlife species, like foxes, may explore the area.

With the use of corridors, such as street trees or green hedges, not only movement of urban wildlife will be promoted, but also important parts of the life-cycle requirements will be provided in the neighborhood. For examples, street trees can for example act as corridors for the dispersal of birds, bats, small mammals and other fauna such as butterflies, moths and beetles (Mullaney et al., 2015), but also provide roosting opportunities for bats (Kalcounis-Rüppell et al., 2005; Straka et al., 2019), or floral resources for pollinating insects (Somme et al., 2016). By providing a variety of life-cycle requirements in a neighborhood this support the survival of species in the area (Weisser and Hauck, 2017). Moreover, if other scenarios (scenario one or two) are incorporated in the design of the area, the life-cycle requirements provided with this scenario can reinforce and support urban wildlife abundance and diversity, also on lower levels and other scenarios (building, plot and block level).

Since scenario three plays out on a higher level (neighborhood level), residents can experience less change in their direct living environment, than if other scenarios (of lower level) are incorporated in the design. Therefore, the experience of nature will be different. In this case, nature cannot be experienced directly from home, but by actively going to the green zones. Residents are thus sometimes required to travel further for nature experience. Therefore, this scenario is less likely to reduce the 'extinction of experience' then scenario one and two. However, if the neighborhood is more traditional, and no other scenarios are used to include nature in the area, this might probably be the only form of nature that the residents could experience. In such neighborhoods, this form of nature is important to reduce the 'extinction of experience'.

To provide the benefits of wildlife corridors for the residents of the neighborhood, management and the aesthetics need to be taken into account in the design phase. Green infrastructure could be perceived negatively if 1) the green areas are designed with negative aesthetics, 2) residents are expected to fund or be involved in the management, when they do not want to be (contrary to shared gardens) and 3) mismanagement (Everett et al., 2018). For positive perception of green infrastructure by the residents of the neighborhood this need to be taken into account.

When designing an area that needs to be part of the surrounding area, space must be cleared for green areas in the design. This space could otherwise be used for more residential buildings, which could potentially be more profitable. However, next to (future) ecological and health benefits, bringing nature into the built environment of a neighborhood can also have economic benefits. Generally property values increase when located near green areas (Hostetler, 2012) and, furthermore, green areas in neighborhoods can allow for (eco)tourisms and recreation.

7. Conclusions

This literature review gives a broad overview on the current state of the academic literature and knowledge on nature-inclusive urban development. With this overview, urban developers, (landscape) architects and planners may use this evidence-based knowledge in practice. In this study, four research questions have been formulated (see chapter 1). The next sections present the conclusions of this review and as such respond to each research question.

7.1. Arguments for nature-inclusive urban development

Based on the literature, it can be concluded that there are three main arguments for nature inclusive urban development (NIUD), stretching from global trends to individual resident benefits. The first argument is that, as described in chapter 2, more people live in urban areas (55%) than in rural areas (45%) and the ongoing urbanization is even expected to keep increasing, both worldwide and in the Netherlands (Centraal Bureau voor de Statistiek, 2016; UN, 2018). This urbanization has consequences on biodiversity in urban area, causing species extinction and homogenization of species communities and thus biodiversity loss (Czech et al., 2000; Guetté et al., 2017; McKinney, 2008, 2006). The threats that urbanization poses for biodiversity in urban areas can be mitigated by NIUD: integrating conservation and protection of landscapes and habitats into the urban design (Severijnen, 2018). The second argument is that a further loss of biodiversity in urban areas will impact how nature will be perceived and conserved by future generations, a direct cause of the so-called 'extinction of experience' (Miller, 2005; Soga and Gaston, 2016) (see chapter 2.3). Including nature in the built could mitigate this effect and reduce the 'extinction of experience'. And third, apart from arguments linked to the conservation and experience of nature, other main arguments to include nature in urban areas are: positive effects on physical/mental health and well-being of urban dwellers, the water cycle and tempering ambient temperatures (see chapter 3.2).

7.2. Exploring NIUD scenarios

To include nature into the design of an urban development area, the planner and urban designer as well as the (landscape) architect needs to keep into account multiple aspects: the demand in the built environment, the target group, purple of the area and what is allowed by legislation. Based on this, a wide range of scenarios to include nature in the urban development can be formulated. Due to the limited scope of this thesis, it is decided to focus on three scenarios that represent the different action perspectives for urban developers and enable to explore how to successfully incorporate nature in the planning phase of the urban development. A first scenario to include nature into the urban area is to meet demands of individual home owners for biodiverse living environments and offer them specific nature-inclusive features in the direct living environment as a proposition for this type of clients. In this scenario nature-inclusive measures can be incorporate at the building and plot level for one house in the residential district. A second scenario is based on the idea that a project developer could accommodate a resident community that all specifically appreciate nature as key condition for their living environment. In this scenario nature-inclusive measures are defined on the neighborhood level. A third scenario takes another viewpoint. Here, an urban development plan is obliged to include an ecological corridor to connect natural areas on both sides of the plan area. By doing this, it allows nature to move though the built environment. These three scenarios are based on different arguments why to incorporate nature into the design, and they also lead to a different layout of the area, and in turn could lead to different nature integrations.

7.3. Scientific evidence on NIUD measures

In chapter 5, a broad review on academic studies is performed where specific attention was paid on the effectiveness of the different measures that can be taken to include nature in the built residential environment in urban areas. The availability of scientific evidence of the NIUD measures differed greatly. Most of the research that is performed on NIUD measures are performed on building level, especially on green roofs. However, there is a lack of sufficient scientific evidence for measures on higher levels. Besides, most studies on the effectiveness of NIUD measures were conducted on birds, only a few studies addressed other species groups like (pollinating) insects and mammals. In order to have a deeper understanding in nature-inclusive urban development and how it can contribute to biodiversity levels in urban areas, more research needs to be performed in a variety of levels and representing the full diversity of wildlife.

Generally speaking, the literature showed that for all measures positive effects on biodiversity levels for wild flora, birds, (pollinating) insects and mammals are found. However, the purpose and effect on the biodiversity levels of the different species groups differs between the measures. While some measures can provide foraging grounds for species, other measures can provide nesting or shelter opportunities or allow migration though and area. For example, street trees can promote the movement of birds and small mammals, while nesting boxes provide nesting opportunities. By providing a range of different life-cycle requirements, and thus different measures, the survival of urban wildlife can be increased.

7.4. Evaluating NIUD scenarios based on the literature

The different NIUD scenarios were evaluated, based on the evidence of the effectiveness of NIUD measures that they include. Scenario 1 encompasses all building and plot level measures: “green roofs”, “green walls”, “nesting boxes” and “private gardens”. Based on the literature it can be concluded that in the case of a low number of households that incorporate these measures the positive effects on biodiversity levels will be limited to organisms that can meet their entire life-cycle requirements in a small area and highly vagile species. The impact of using this scenario on biodiversity levels is dependent on the number of households that are interested in a block or neighborhood. When more households are interested, the positive effects on biodiversity levels will be much more substantial, while the positive effects on biodiversity levels will be minimal when only a few households are interested.

Scenario 2, which is aimed at creating a biodiverse habitat on community level encompasses the NIUD measures “private gardens” and “collective green. Literature shows that by connecting gardens, a higher connectivity, larger area and more possibilities for life-cycle requirements in the area will be created, which is beneficial for species richness and the migration of urban wildlife. Also, shared gardens may enhance biodiversity on community level. The connection of private and shared gardens, can possibly support a higher biodiversity than without a connection (scenario 1). However, the amount participation from urban dwellers is determinative in the biodiversity conservation.

Scenario 3, in which a wildlife corridor makes part of the urban development, can be used to support migration of wildlife (as planned), but may also be used to separate of “soft” and “hard” infrastructure, respectively green and water (including opportunities for walking and cycling) versus roads for motorized traffic and housing. Besides, a wildlife corridor in the residential district can increase the opportunity that extraordinary wildlife species, like foxes, may explore the area. Combining a wildlife corridor (scenario 3) with nature-inclusive housing (scenario 1) and community gardens (scenario 2) will ensure a large variety of life-cycle attributes in the residential neighborhood, which is the basis for a highly biodiverse and experienceable living area.

8. Recommendation for an evidence-based approach for nature-inclusive urban development

Urban ecology, especially the ecology of the built-up matrix (nature-inclusive urban development) is still a relatively new field in biology and urban planning. However, with the ongoing urbanization and its impact on biodiversity, NIUD can offer a great potential to support and increase biodiversity in urban areas. In the last decades new measures are invented and implemented. Nevertheless, there is still much room for innovations, research and approaches on nature-inclusive urban development and their measures.

8.1. Choose target species and meet life cycle requirements

First of all, to accommodate wildlife in residential districts it is important to understand that the characteristics (e.g., shelter, foraging or nesting requirements) that wildlife needs for its survival are often species-specific. Therefore, it is recommended for an urban planner or (landscape)architect to select a set of target species (e.g., the Big Five) at the start of the designing phase of the urban development. For example, one may select iconic species that are currently declining in urban areas (e.g., House sparrow). Next, the requirements of these species should be considered as part of the (landscape) architectural design. By doing so the potential conflict between design and conservation will be avoided, which nowadays often still is the case (Weisser and Hauck, 2017). If the selected species are considered umbrella species for a specific wildlife community or biotope, in addition to the initial target species multiple species will benefit from such nature-inclusive architectural design (Weisser and Hauck, 2017).

A possible useful way to meet the species-specific needs of the target species is by identifying the species life-cycle requirements. As mentioned before, for the biodiversity and survival of species it is important to focus on each phase in its life-cycle, from birth to reproduction. In other words, it is necessary to provide the species-specific requirements for foraging, nesting, shelter and migrating habitats in the plan area. An example of possible useful information for landscape architects and city planners is shown in box 2 (modified from Weisser and Hauck, 2017). By obtaining these species-specific requirements, information at the start of the designing phase the urban planner or (landscape) architect can incorporate this in the

Box 2: Recommended information about target-species to inform (landscape) architects and urban planners and developers (modified from Weisser and Hauck, 2017).

- General characteristics of target species
  - general habitat characteristics
  - natural enemies
  - conservation status
  - ecosystem service provisioning
- Life cycle
  - critical feeding needs of target species
  - critical nesting needs of target species

design. This ensures that all the requirements (foraging, nesting and shelter) can be met and the chance of survival of a species is higher.

8.2. Recommendations for future research

NIUD on housing, block and residential district level, and representing the full diversity of wildlife

An important finding from this literature report is that most of the research that is performed on NIUD-measures is conducted on the building and plot level, in particular at green roofs. However, research is lacking when it comes to the use of NIUD on block, street neighborhood level. It is recommended that in future research these levels are taken into account. Also, as concluded in this literature review, most scientific research is performed on bird species, research on other species groups such as (pollinating) insects and mammals are still scarce and need further investigation.

Effects of upscaling and interlinking NIUD measures

Strikingly, there is only little research performed on the biodiversity levels on private gardens while private gardens collectively comprise the largest green space in urban areas. More research is needed on the configuration of gardens and how this affects the urban wildlife and the biodiversity levels. Also, when investigating a NIUD measure that is used on building level the effect on biodiversity levels and urban wildlife on higher levels need to be taken into account. For example, how does the implementation of measures on the building levels, such as green roofs and walls, affect the biodiversity on neighborhood level? Therefore, it is recommended that in future research these levels are taken into account in order to improve NIUD on all levels.

From NIUD measure to NIUD habitat system

Next to the need of more research on higher levels, most research that is performed solely focused on single measures. However, it would be useful to investigate what the effect of combining measures and scenarios is on biodiversity levels to include nature in urban areas. By combining scenarios and/or measures, it could be easier to meet the requirements of the life-cycle of species. One example of combing scenarios could be the combination of a bees nesting boxes with a green wall. For example, the combination of a nesting box (breeding place) and a green wall (food source for pollinators) would incorporate more life-cycle requirements than either measures on their own. If the design does not cover all the critical needs of the target species, in this case pollinators, the plan to establish these species in the area may fail. However, since green walls have high moisture levels which can have an impact on the suitability for artificial nests, further research is needed if this combination is indeed beneficial (El Ghomari, 2019). Another important result is that when green roofs are too high, they can become isolated. A possible solution for this could be to connect the green roof to the adjacent nature with the use of green walls. Since corridors are known as useful solutions for enhancing biodiversity in urban areas (Vergnes et al., 2013), they can prove to be useful to connect isolated roofs to the adjacent nature. To investigate if green walls can act as a corridor to green roofs, an analysis of the microclimatic conditions of green walls and roofs is required (Mayrand and Clergeau, 2018). With this information it will be able to identify if species that colonize green walls are also able to colonize green roofs. To conclude, by combining measures the chance of NIUD to be successful can possibly be increased.

Communication

At last, more communication between urban planners, (landscape) architect and ecologists would help to make NIUD more successful. Landscape architects are often not experts in ecology and therefore rely on the knowledge of ecologists. In turn, ecologists are not experts in design and may not know what problems (landscape) architects are facing. If we want to successfully include nature into the urban development this gap needs to be closed.

9. References

Alvey, A.A., 2006. Promoting and preserving biodiversity in the urban forest. Urban Forestry & Urban Greening 5, 195–201. https://doi.org/10.1016/j.ufug.2006.09.003

Apfelbeck, B., Snep, R.P.H., Hauck, T.E., Ferguson, J., Holy, M., Jakoby, C., Scott MacIvor, J., Schär, L., Taylor, M., Weisser, W.W., 2020. Designing wildlife-inclusive cities that support human-animal co-existence. Landscape and Urban Planning 200, 103817. https://doi.org/10.1016/j.landurbplan.2020.103817

Aronson, M.F.J., La Sorte, F.A., Nilon, C.H., Katti, M., Goddard, M.A., Lepczyk, C.A., Warren, P.S., Williams, N.S.G., Cilliers, S., Clarkson, B., Dobbs, C., Dolan, R., Hedblom, M., Klotz, S., Kooijmans, J.L., Kühn, I., MacGregor-Fors, I., McDonnell, M., Mörtberg, U., Pyšek, P., Siebert, S., Sushinsky, J., Werner, P., Winter, M., 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc. R. Soc. B 281, 20133330. https://doi.org/10.1098/rspb.2013.3330

Atkins, E., 2019. Biodiversity value of urban hedges. The Ecology of Hedgerows and Field Margins 263–272.

Atkins, E.R., Swetnam, R.D., Mitchell, P., Dover, J.W., 2018. Surveying small mammals in urban hedges. Mammal Communications 4, 7–15.

Baker, P.J., Harris, S., 2007. Urban mammals: what does the future hold? An analysis of the factors affecting patterns of use of residential gardens in Great Britain. Mammal Review 0, 070611094052001-??? https://doi.org/10.1111/j.1365-2907.2007.00102.x

Balaji, S., 2014. Artificial nest box for house sparrow: An apt method to save the dwindling species in an urban environment. Int. J. Biodivers. Conserv. 6, 194–198. https://doi.org/10.5897/IJBC2014.0689

Baldock, K.C.R., Goddard, M.A., Hicks, D.M., Kunin, W.E., Mitschunas, N., Osgathorpe, L.M., Potts, S.G., Robertson, K.M., Scott, A.V., Stone, G.N., Vaughan, I.P., Memmott, J., 2015. Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. Proc. R. Soc. B 282, 20142849. https://doi.org/10.1098/rspb.2014.2849

Banting, D., Doshi, H., Li, J., Missios, P., 2005. Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto. Ryerson University, Toronto.

Barot, S., Abbadie, L., Auclerc, A., Barthélémy, C., Bérille, E., Billet, P., Clergeau, P., Consales, J.-N., Deschamp-Cottin, M., David, A., Devigne, C., Dham, V., Dusza, Y., Gaillard, A., Gonzalez, E., Hédont, M., Labarraque, D., Le Bastard, A.-M., Morel, J.-L., Petit-Berghem, Y., Rémy, E., Rochelle-Newall, E., Veyrières, M., 2019. Urban ecology, stakeholders and the future of ecology. Science of The Total Environment 667, 475–484. https://doi.org/10.1016/j.scitotenv.2019.02.410

Beatley, T., Newman, P., 2013. Biophilic Cities Are Sustainable, Resilient Cities. Sustainability 5, 3328–3345. https://doi.org/10.3390/su5083328

Beissinger, S.R., Osborne, D.R., 1982. Effects of Urbanization on Avian Community Organization. The Condor 84, 75. https://doi.org/10.2307/1367825

Bergey, E.A., 2019. Dispersal of a non-native land snail across a residential area is modified by yard management and movement barriers. Urban Ecosyst 10.

Bhullar, S., Majer, J., 2000. Arthropods on street trees: a food resource for wildlife. Pacific Conservation Biology 171–173.

Bixler, R.D., Floyd, M.F., Hammitt, W.E., 2002. Environmental Socialization: Quantitative Tests of the Childhood Play Hypothesis. Environment and Behavior 34, 795–818. https://doi.org/10.1177/001391602237248

Bland, R.L., Tully, J., Greenwood, J.J.D., 2004. Birds breeding in British gardens: an underestimated population? Bird Study 51, 97–106. https://doi.org/10.1080/00063650409461340

Botzat, A., Fischer, L.K., Kowarik, I., 2016. Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. Global Environmental Change 39, 220–233. https://doi.org/10.1016/j.gloenvcha.2016.04.008

Braschler, B., Gilgado, J.D., Zwahlen, V., Rusterholz, H.-P., Buchholz, S., Baur, B., 2020. Ground-dwelling invertebrate diversity in domestic gardens along a rural-urban gradient: Landscape characteristics are more important than garden characteristics. PLoS ONE 15, e0240061. https://doi.org/10.1371/journal.pone.0240061

Breeze, T.D., Roberts, S.P.M., Potts, S.G., 2012. The Decline of England's Bees. University of Reading.

Brenneisen, S., 2006. Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland 4, 10.

Cannon, A., 1999. The significance of private gardens for bird conservation. Bird Conservation International 9, 287–297. https://doi.org/10.1017/S095927090000349X

Cannon, A.R., Chamberlain, D.E., Toms, M.P., Hatchwell, B.J., Gaston, K.J., 2005. Trends in the use of private gardens by wild birds in Great Britain 1995-2002: Garden bird trends. Journal of Applied Ecology 42, 659–671. https://doi.org/10.1111/j.1365-2664.2005.01050.x

Centraal Bureau voor de Statistiek, 2018. Populaties van 13 van de 20 stadsvogels afgenomen [WWW Document]. Centraal Bureau voor de Statistiek. URL https://www.cbs.nl/nl-nl/nieuws/2018/49/populaties-van-13-van-de-20-stadsvogels-afgenomen (accessed 7.1.20).

Centraal Bureau voor de Statistiek, 2016. PBL/CBS prognose: Groei steden zet door [WWW Document]. Centraal Bureau voor de Statistiek. URL https://www.cbs.nl/nl-nl/nieuws/2016/37/pbl-cbs-prognose-groei-steden-zet-door (accessed 6.9.20).

Chamberlain, D.E., Cannon, A.R., Toms, M.P., 2004. Associations of garden birds with gradients in garden habitat and local habitat. Ecography 27, 589–600. https://doi.org/10.1111/j.0906-7590.2004.03984.x

Chamberlain, D.E., Cannon, A.R., Toms, M.P., Leech, D.I., Hatchwell, B.J., Gaston, K.J., 2009. Avian productivity in urban landscapes: a review and meta-analysis. Ibis 151, 1–18. https://doi.org/10.1111/j.1474-919X.2008.00899.x

Champion, T. (Ed.), 2001. Urbanization, Suburbanization, Counterurbanization and Reurbanization, in: Handbook of Urban Studies. SAGE, London ; Thousand Oaks, Calif.

Chiquet, C., Dover, J.W., Mitchell, P., 2013. Birds and the urban environment: the value of green walls. Urban Ecosyst 16, 453–462. https://doi.org/10.1007/s11252-012-0277-9

Clark, P.J., Reed, J.M., Chew, F.S., 2007. Effects of urbanization on butterfly species richness, guild structure, and rarity. Urban Ecosyst 10, 321–337. https://doi.org/10.1007/s11252-007-0029-4

Coder, K.D., 1998. Tree Root Growth Control Series: Tree Roots And Infrastructure Damage. University of Georgia.

Colding, J., Barthel, S., 2013. The potential of 'Urban Green Commons' in the resilience building of cities. Ecological Economics 86, 156–166. https://doi.org/10.1016/j.ecolecon.2012.10.016

Colding, J., Barthel, S., Bendt, P., Snep, R., van der Knaap, W., Ernstson, H., 2013. Urban green commons: Insights on urban common property systems. Global Environmental Change 23, 1039–1051. https://doi.org/10.1016/j.gloenvcha.2013.05.006

Cooke, A.S., 1980. Observations on how close certain passerine species will tolerate an approaching human in rural and suburban areas. Biological Conservation 18, 85–88. https://doi.org/10.1016/0006-3207(80)90072-5

Cortinovis, C., Geneletti, D., 2019. A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. Ecosystem Services 38, 100946. https://doi.org/10.1016/j.ecoser.2019.100946

Czech, B., Krausman, P.R., Devers, P.K., 2000. Economic Associations among Causes of Species Endangerment in the United States. BioScience 50, 593. https://doi.org/10.1641/0006-3568(2000)050[0593:EAACOS]2.0.CO;2

Daniels, G.D., Kirkpatrick, J.B., 2006. Does variation in garden characteristics influence the conservation of birds in suburbia? Biological Conservation 133, 326–335. https://doi.org/10.1016/j.biocon.2006.06.011

Day, T.D., 1995. Bird species composition and abundance in relation to native plants in urban gardens, Hamilton, New Zealand 12.

de Vries, S., Maas, J., Kramer, H., 2009. Effecten van nabije natuur op gezondheid en welzijn; mogelijke mechanismen achter de relatie tussen groen in de woonomgeving en gezondheid. Wettelijke Onderzoekstaken Natuur & Milieu WOt-rapport 91.

de Vries, S., Verheij, R.A., Groenewegen, P.P., Spreeuwenberg, P., 2003. Natural Environments—Healthy Environments? An Exploratory Analysis of the Relationship between Greenspace and Health. Environ Plan A 35, 1717–1731. https://doi.org/10.1068/a35111

Dennis, M., James, P., 2016a. User participation in urban green commons: Exploring the links between access, voluntarism, biodiversity and well being. Urban Forestry & Urban Greening 15, 22–31. https://doi.org/10.1016/j.ufug.2015.11.009

Dennis, M., James, P., 2016b. Site-specific factors in the production of local urban ecosystem services: A case study of community-managed green space. Ecosystem Services 17, 208–216. https://doi.org/10.1016/j.ecoser.2016.01.003

Ditchkoff, S.S., Saalfeld, S.T., Gibson, C.J., 2006. Animal behavior in urban ecosystems: Modifications due to human-induced stress. Urban Ecosyst 9, 5–12. https://doi.org/10.1007/s11252-006-3262-3

Dunnett, N., 2006. Green roofs for biodiversity: reconciling aesthetics with ecology. Conference Proceedings 12.

Dunnett, N., Qasim, M., 2000. Perceived Benefits to Human Well-being of Urban Gardens. horttech 10, 40–45. https://doi.org/10.21273/HORTTECH.10.1.40

El Ghomari, S., 2019. The Potential of Living Walls to Host Pollinator Habitat. Uppsala University.

Emmanuel, R., Loconsole, A., 2015. Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK. Landscape and Urban Planning 138, 71–86. https://doi.org/10.1016/j.landurbplan.2015.02.012

English Nature, 2003. Green roofs: their existing status and potential for conserving biodiversity in urban areas (English Nature Report No. 498). Peterborough.

Evans, J.P., 2007. Wildlife Corridors: An Urban Political Ecology. Local Environment 12, 129–152. https://doi.org/10.1080/13549830601133169

Everett, G., Lamond, J.E., Morzillo, A.T., Matsler, A.M., Chan, F.K.S., 2018. Delivering Green Streets: an exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon: An exploration of changing perceptions in Portland, Oregon. J Flood Risk Management 11, S973–S985. https://doi.org/10.1111/jfr3.12225

Fernandez-Canero, R., Gonzalez-Redondo, P., 2010. Green Roofs as a Habitat for Birds: A Review. Journal of Animal and Veterinary Advances 9, 2041–2052.

Fernández‐Juricic, E., 2000. Avifaunal Use of Wooded Streets in an Urban Landscape. Conservation Biology 14, 513–521. https://doi.org/10.1046/j.1523-1739.2000.98600.x

Fernández-Juricic, E., Tellería, J.L., 2000. Effects of human disturbance on spatial and temporal feeding patterns of Blackbird Turdus merula in urban parks in Madrid, Spain. Bird Study 47, 13–21. https://doi.org/10.1080/00063650009461156

Feyisa, G.L., Dons, K., Meilby, H., 2014. Efficiency of parks in mitigating urban heat island effect: An example from Addis Ababa. Landscape and Urban Planning 123, 87–95. https://doi.org/10.1016/j.landurbplan.2013.12.008

Fortel, L., Henry, M., Guilbaud, L., Mouret, H., Vaissière, B.E., 2016. Use of human-made nesting structures by wild bees in an urban environment. J Insect Conserv 20, 239–253. https://doi.org/10.1007/s10841-016-9857-y

Francis, R.A., 2011. Wall ecology: A frontier for urban biodiversity and ecological engineering. Progress in Physical Geography: Earth and Environment 35, 43–63. https://doi.org/10.1177/0309133310385166

Frid, A., Dill, L.M., 2002. Human-caused Disturbance Stimuli as a Form of Predation Risk. CE 6, art11. https://doi.org/10.5751/ES-00404-060111

Fukase, J., 2016. Increased pollinator activity in urban gardens with more native flora. Appl Ecol Env Res 14, 297–310. https://doi.org/10.15666/aeer/1401_297310

Galantinho, A., Herrera, J.M., Eufrázio, S., Silva, C., Carvalho, F., Alpizar-Jara, R., Mira, A., 2020. Road verges provide connectivity for small mammals: A case study with wood mice (Apodemus sylvaticus) in an agro-silvo pastoral system. Journal of Environmental Management 258, 110033. https://doi.org/10.1016/j.jenvman.2019.110033

Gardlund, T., 1942. Industrialismens samhalle.

Gemeente Amsterdam, 2020. Werkboek Integrale Ontwerpmethode Openbare Ruimte. Amsterdam.

Getter, K.L., Rowe, D.B., 2006. The Role of Extensive Green Roofs in Sustainable Development. HortSci 41, 1276–1285. https://doi.org/10.21273/HORTSCI.41.5.1276

Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S., 2007. Adapting Cities for Climate Change: The Role of the Green Infrastructure. built environ 33, 115–133. https://doi.org/10.2148/benv.33.1.115

Glista, D.J., DeVault, T.L., DeWoody, J.A., 2009. A review of mitigation measures for reducing wildlife mortality on roadways. Landscape and Urban Planning 91, 1–7.

Goddard, M.A., Dougill, A.J., Benton, T.G., 2010. Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology & Evolution 25, 90–98. https://doi.org/10.1016/j.tree.2009.07.016

Goffin, B., 2019. The effect of artificial nesting sites on the populations of ten Dutch breeding birds. Wageningen University.

Griffiths, S.R., Lumsden, L.F., Robert, K.A., Lentini, P.E., 2020. Nest boxes do not cause a shift in bat community composition in an urbanised landscape. Sci Rep 10, 6210. https://doi.org/10.1038/s41598-020-63003-w

Gromke, C., Ruck, B., 2007. Influence of trees on the dispersion of pollutants in an urban street canyon—Experimental investigation of the flow and concentration field. Atmospheric Environment 41, 3287–3302. https://doi.org/10.1016/j.atmosenv.2006.12.043

Groth, P., Miller, R., Nadkarni, N., Riley, M., Shoup, L., 2016. Quantifying the greenhouse gas benefits of urban parks. The Trust for Public Land, San Francisco.

Guetté, A., Gaüzère, P., Devictor, V., Jiguet, F., Godet, L., 2017. Measuring the synanthropy of species and communities to monitor the effects of urbanization on biodiversity. Ecological Indicators 79, 139–154. https://doi.org/10.1016/j.ecolind.2017.04.018

Gunawardena, K.R., Wells, M.J., Kershaw, T., 2017. Utilising green and bluespace to mitigate urban heat island intensity. Science of The Total Environment 584–585, 1040–1055.

https://doi.org/10.1016/j.scitotenv.2017.01.158

Hartig, T., Mitchell, R., de Vries, S., Frumkin, H., 2014. Nature and Health. Annu. Rev. Public Health 35, 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hostetler, M.E. (Author), 2012. Green Leap : A Primer for Conserving Biodiversity in Subdivision Development. University of California Press, London.

Ives, C.D., Lentini, P.E., Threlfall, C.G., Ikin, K., Shanahan, D.F., Garrard, G.E., Bekessy, S.A., Fuller, R.A., Mumaw, L., Rayner, L., Rowe, R., Valentine, L.E., Kendal, D., 2016. Cities are hotspots for threatened species: The importance of cities for threatened species. Global Ecology and Biogeography 25, 117–126. https://doi.org/10.1111/geb.12404

Kalcounis-Rüppell, M.C., Psyllakis, J.M., Brigham, R.M., 2005. Tree roost selection by bats: an empirical synthesis using meta-analysis. Wildlife Society Bulletin 33, 1123–1132. https://doi.org/10.2193/0091-7648(2005)33[1123:TRSBBA]2.0.CO;2

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L.J., Paus, T., Berman, M.G., 2015. Neighborhood greenspace and health in a large urban center. Sci Rep 5, 11610. https://doi.org/10.1038/srep11610

Kendle, A.D., Rose, J.E., 2000. The aliens have landed! What are the justi®cations for `native only' policies in landscape plantings? Landscape and Urban Planning 13.

Köhler, M., 2008. Green facades—a view back and some visions. Urban Ecosyst 11, 423–436. https://doi.org/10.1007/s11252-008-0063-x

Kunz, T.H., Braun de Torrez, E., Bauer, D., Lobova, T., Fleming, T.H., 2011. Ecosystem services provided by bats: Ecosystem services provided by bats. Annals of the New York Academy of Sciences 1223, 1–38. https://doi.org/10.1111/j.1749-6632.2011.06004.x

Lepczyk, C.A., Aronson, M.F.J., Evans, K.L., Goddard, M.A., Lerman, S.B., MacIvor, J.S., 2017. Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity Conservation. BioScience 67, 799–807. https://doi.org/10.1093/biosci/bix079

Li, X., Zhou, W., Ouyang, Z., Xu, W., Zheng, H., 2012. Spatial pattern of greenspace affects land surface temperature: evidence from the heavily urbanized Beijing metropolitan area, China. Landscape Ecol 27, 887–898. https://doi.org/10.1007/s10980-012-9731-6

Long, L.C., Frank, S.D., 2020. Risk of bird predation and defoliating insect abundance are greater in urban forest fragments than street trees. Urban Ecosyst 23, 519–531. https://doi.org/10.1007/s11252-020-00939-x

Longcore, T., Rich, C., 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2, 191–198. https://doi.org/10.1890/1540-9295(2004)002[0191:ELP]2.0.CO;2

Lundholm, J.T., 2005. Green Roofs and Facades: A Habitat Template Approach. The Third Annual Greening Rooftops for Sustainable Communities Conference 4, 87–101.

Maas, J., Verheij, R.A., Groenewegen, P.P., de Vries, S., Spreeuwenberg, P., 2006. Green space, urbanity, and health: how strong is the relation? Journal of Epidemiology & Community Health 60, 587–592. https://doi.org/10.1136/jech.2005.043125

MacIvor, J.S., Lundholm, J., 2011. Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. Urban Ecosyst 14, 225–241. https://doi.org/10.1007/s11252-010-0149-0

MacIvor, J.S., Packer, L., 2015. 'Bee Hotels' as Tools for Native Pollinator Conservation: A Premature Verdict? PLoS ONE 10, e0122126. https://doi.org/10.1371/journal.pone.0122126

Madre, F., Clergeau, P., Machon, N., Vergnes, A., 2015. Building biodiversity: Vegetated façades as habitats for spider and beetle assemblages. Global Ecology and Conservation 3, 222–233. https://doi.org/10.1016/j.gecco.2014.11.016

Madre, F., Vergnes, A., Machon, N., Clergeau, P., 2014. Green roofs as habitats for wild plant species in urban landscapes: First insights from a large-scale sampling. Landscape and Urban Planning 122, 100–107. https://doi.org/10.1016/j.landurbplan.2013.11.012

Manso, M., Castro-Gomes, J., 2015. Green wall systems: A review of their characteristics. Renewable and Sustainable Energy Reviews 41, 863–871. https://doi.org/10.1016/j.rser.2014.07.203

Markovchick-Nicholls, L., Regan, H.M., Deutschman, D.H., Widyanata, A., Martin, B., Noreke, L., Ann Hunt, T., 2008. Relationships between Human Disturbance and Wildlife Land Use in Urban Habitat Fragments: *Human Disturbance in Habitat Fragments*. Conservation Biology 22, 99–109. https://doi.org/10.1111/j.1523-1739.2007.00846.x

Mayrand, F., Clergeau, P., 2018. Green Roofs and Green Walls for Biodiversity Conservation: A Contribution to Urban Connectivity? Sustainability 10, 985. https://doi.org/10.3390/su10040985

Mayrand, F., Clergeau, P., Vergnes, A., Madre, F., 2018. Vertical Greening Systems as Habitat for Biodiversity. Nature based strategies for urban and building sustainability 227–237. https://doi.org/10.1016/B978-0-12-812150-4.00021-5

McKinney, M.L., 2008. Effects of urbanization on species richness: A review of plants and animals. Urban Ecosyst 11, 161–176. https://doi.org/10.1007/s11252-007-0045-4

McKinney, M.L., 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127, 247–260. https://doi.org/10.1016/j.biocon.2005.09.005

McKinney, M.L., 2002. Urbanization, Biodiversity, and Conservation. BioScience 52, 883. https://doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2

Mering, E.D., Chambers, C.L., 2014. Thinking outside the box: A review of artificial roosts for bats: Artificial Bat Roosts. Wildl. Soc. Bull. 38, 741–751. https://doi.org/10.1002/wsb.461

Miller, J.R., 2005. Biodiversity conservation and the extinction of experience. Trends in Ecology & Evolution 20, 430–434. https://doi.org/10.1016/j.tree.2005.05.013

Mulder, J.L., 2012. De boommarterbrug bij De Bilt – een half jaar monitoring. Bureau Mulder-natuurlijk, De Bilt.

Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in growing street trees in paved urban environments. Landscape and Urban Planning 134, 157–166. https://doi.org/10.1016/j.landurbplan.2014.10.013

Newman, P., 2002. Urban Planning in Europe: International Competition, National Systems and Planning Projects, 1st ed. Routledge. https://doi.org/10.4324/9780203427941

Newport, J., Shorthouse, D.J., Manning, A.D., 2014. The effects of light and noise from urban development on biodiversity: Implications for protected areas in Australia. Ecol Manag Restor 15, 204–214. https://doi.org/10.1111/emr.12120

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., Mihalakakou, G., 2001. Analysis of the green roof thermal properties and investigation of its energy performance. Energy and Buildings 33, 719–729. https://doi.org/10.1016/S0378-7788(01)00062-7

Nisbet, E.K., Shaw, D.W., Lachance, D.G., 2020. Connectedness With Nearby Nature and Well-Being. Front. Sustain. Cities 2, 18. https://doi.org/10.3389/frsc.2020.00018

Nystrom, J., 1992. The Cyclical Urbanization Model. A Critical Analysis. Geografiska Annaler. Series B, Human Geography 74, 133. https://doi.org/10.2307/490569

Oliveira, S., Andrade, H., Vaz, T., 2011. The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. Building and Environment 46, 2186–2194. https://doi.org/10.1016/j.buildenv.2011.04.034

Paker, Y., Yom-Tov, Y., Alon-Mozes, T., Barnea, A., 2014. The effect of plant richness and urban garden structure on bird species richness, diversity and community structure. Landscape and Urban Planning 122, 186–195. https://doi.org/10.1016/j.landurbplan.2013.10.005

PBL, 2016. Cities in the Netherlands [WWW Document]. PBL Planbureau voor de Leefomgeving. URL https://www.pbl.nl/en/publications/cities-in-the-netherlands (accessed 6.17.20).

Pearce, H., Walters, C.L., 2012. Do Green Roofs Provide Habitat for Bats in Urban Areas? Acta Chiropterologica 14, 469–478. https://doi.org/10.3161/150811012X661774

Pena, J.C. de C., Martello, F., Ribeiro, M.C., Armitage, R.A., Young, R.J., Rodrigues, M., 2017. Street trees reduce the negative effects of urbanization on birds. PLoS ONE 12, e0174484. https://doi.org/10.1371/journal.pone.0174484

Perre, P., Loyola, R.D., Lewinsohn, T.M., Almeida-Neto, M., 2011. Insects on urban plants: contrasting the flower head feeding assemblages on native and exotic hosts. Urban Ecosyst 14, 711–722. https://doi.org/10.1007/s11252-011-0179-2

Potts, S.G., Vulliamy, B., Dafni, A., Ne'eman, G., Willmer, P., 2003. Linking bees and flowers: How do floral communities structure pollinator communities? Ecology 84, 2628–2642. https://doi.org/10.1890/02-0136

Pugh, T.A.M., MacKenzie, A.R., Whyatt, J.D., Hewitt, C.N., 2012. Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons. Environmental Science & Technology 7692–7699.

Pyle, R., 1993. The thunder tree: lessons from an urban wildland. Boston MA: Houghton Mifflin.

Racelis, A., Vacek, A.T., Goolsby, C., Brush, J., Goolsby, J.A., 2013. Arthropod abundance and diversity in street trees of south Texas, USA. Subtropical Plant Sciences 65, 31–37.

Rice, E.L., Kelting, R.W., 1955. The Species-Area Curve. Ecology 36, 7–11.

Roehr, D., Laurenz, J., 2008. Living skins: environmental benefits of green envelopes in the city context. WIT Transactions on Ecology and the Environment 149–158.

Rueegger, N., 2016. Bat Boxes — A Review of Their Use and Application, Past, Present and Future. Acta Chiropterologica 18, 279–299. https://doi.org/10.3161/15081109ACC2016.18.1.017

Russo, D., Ancillotto, L., 2015. Sensitivity of bats to urbanization: a review. Mammalian Biology 80, 205–212. https://doi.org/10.1016/j.mambio.2014.10.003

Salisbury, A., Armitage, J., Bostock, H., Perry, J., Tatchell, M., Thompson, K., 2015. Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? J Appl Ecol 52, 1156–1164. https://doi.org/10.1111/1365-2664.12499

Savard, J.-P.L., Clergeau, P., Mennechez, G., 2000. Biodiversity concepts and urban ecosystems. Landscape and Urban Planning 48, 131–142. https://doi.org/10.1016/S0169-2046(00)00037-2

Severijnen, P., 2018. Maximising the biodiversity potential of Rivierenwijk, Utrecht by landscape architecture design. Wageningen University.

Silvera Seamans, G., 2013. Mainstreaming the environmental benefits of street trees. Urban Forestry & Urban Greening 12, 2–11. https://doi.org/10.1016/j.ufug.2012.08.004

Smith, D.J., van der Ree, R., Rosell, C., 2015. Chapter 21 - Wildlife crossing structures: An effective strategy to restore or maintain wildlife connectivity across roads, in: Handbook of Road Ecology. John Wiley & Sons, p. 551.

Smith, Richard M., Gaston, K.J., Warren, P.H., Thompson, K., 2006a. Urban domestic gardens (VIII) : environmental correlates of invertebrate abundance. Biodivers Conserv 15, 2515–2545. https://doi.org/10.1007/s10531-005-2784-y

Smith, R.M., Thompson, K., Hodgson, J.G., Warren, P.H., Gaston, K.J., 2006. Urban domestic gardens (IX):

Composition and richness of the vascular plant flora, and implications for native biodiversity. Biological Conservation 129, 312–322. https://doi.org/10.1016/j.biocon.2005.10.045

Smith, Richard M., Warren, P.H., Thompson, K., Gaston, K.J., 2006b. Urban domestic gardens (VI): environmental correlates of invertebrate species richness. Biodivers Conserv 15, 2415–2438. https://doi.org/10.1007/s10531-004-5014-0

Soga, M., Gaston, K., Yamaura, Y., Kurisu, K., Hanaki, K., 2016. Both Direct and Vicarious Experiences of Nature Affect Children's Willingness to Conserve Biodiversity. IJERPH 13, 529. https://doi.org/10.3390/ijerph13060529

Soga, M., Gaston, K.J., 2016. Extinction of experience: the loss of human-nature interactions. Front Ecol Environ 14, 94–101. https://doi.org/10.1002/fee.1225

Somme, L., Moquet, L., Quinet, M., Vanderplanck, M., Michez, D., Lognay, G., Jacquemart, A.-L., 2016. Food in a row: urban trees offer valuable floral resources to pollinating insects. Urban Ecosyst 19, 1149–1161. https://doi.org/10.1007/s11252-016-0555-z

Stovin, V., 2010. The potential of green roofs to manage Urban Stormwater: The potential of green roofs to manage Urban Stormwater. Water and Environment Journal 24, 192–199. https://doi.org/10.1111/j.1747-6593.2009.00174.x

Straka, T.M., Wolf, M., Gras, P., Buchholz, S., Voigt, C.C., 2019. Tree Cover Mediates the Effect of Artificial Light on Urban Bats. Front. Ecol. Evol. 7, 91. https://doi.org/10.3389/fevo.2019.00091

Sugiyama, T., Leslie, E., Giles-Corti, B., Owen, N., 2008. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? Journal of Epidemiology & Community Health 62, e9–e9. https://doi.org/10.1136/jech.2007.064287

Tallis, M., Taylor, G., Sinnett, D., Freer-Smith, P., 2011. Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments. Landscape and Urban Planning 103, 129–138. https://doi.org/10.1016/j.landurbplan.2011.07.003

Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M.C., Schwager, M., Jeltsch, F., 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures: Animal species diversity driven by habitat heterogeneity. Journal of Biogeography 31, 79–92. https://doi.org/10.1046/j.0305-0270.2003.00994.x

Thompson, P.S., Greenwood, J.J.D., Greenaway, K., 1993. Birds in European gardens in the winter and spring of 1988–89. Bird Study 40, 120–134. https://doi.org/10.1080/00063659309477137

Tonietto, R., Fant, J., Ascher, J., Ellis, K., Larkin, D., 2011. A comparison of bee communities of Chicago green roofs, parks and prairies. Landscape and Urban Planning 103, 102–108. https://doi.org/10.1016/j.landurbplan.2011.07.004

Turner, W.R., Nakamura, T., Dinetti, M., 2004. Global Urbanization and the Separation of Humans from Nature. BioScience 54, 585. https://doi.org/10.1641/0006-3568(2004)054[0585:GUATSO]2.0.CO;2

UN, 2018. World urbanization prospects 2018. New York.

van den Berg, L., Drewett, R., Klaassen, L.H., Rossi, A., Vijverberg, C.H.T., 1982. Stages of Urban Development, in: A Study of Growth and Decline. Elsevier, pp. 24–45. https://doi.org/10.1016/B978-0-08-023156-3.50009-7

van der Mei, T., Dijkstra, V., 2011. Bat populations thriving [WWW Document]. Statistics Netherlands. URL https://www.cbs.nl/en-gb/news/2011/28/bat-populations-thriving (accessed 7.27.20).

van der Ree, R., van der Grift, E.A., Gulle, N., Holland, K., Mata, C., Suarez, F., 2007. An international review of the use and effectiveness of underpasses and overpasses designed to increase the permeability of

roads for wildlife. International conference on ecology and transportation 20–25.
van Heezik, Y., Freeman, C., Porter, S., Dickinson, K.J.M., 2013. Garden Size, Householder Knowledge, and Socio-Economic Status Influence Plant and Bird Diversity at the Scale of Individual Gardens. Ecosystems 16, 1442–1454. https://doi.org/10.1007/s10021-013-9694-8
Van Helden, B.E., Close, P.G., Steven, R., 2020. Mammal conservation in a changing world: can urban gardens play a role? Urban Ecosyst 23, 555–567. https://doi.org/10.1007/s11252-020-00935-1
Vercauteren, M., Geurts, K., Boers, K., Criel, D., Vercayie, D., 2015. Handleiding eekhoordbruggen aanleggen. Natuurpunt Studie, Mechelen.
Vergnes, A., Kerbiriou, C., Clergeau, P., 2013. Ecological corridors also operate in an urban matrix: A test case with garden shrews. Urban Ecosyst 16, 511–525. https://doi.org/10.1007/s11252-013-0289-0
Villemey, A., Jeusset, A., Vargac, M., Bertheau, Y., Coulon, A., Touroult, J., Vanpeene, S., Castagneyrol, B., Jactel, H., Witte, I., Deniaud, N., Flamerie De Lachapelle, F., Jaslier, E., Roy, V., Guinard, E., Le Mitouard, E., Rauel, V., Sordello, R., 2018. Can linear transportation infrastructure verges constitute a habitat and/or a corridor for insects in temperate landscapes? A systematic review. Environ Evid 7, 5. https://doi.org/10.1186/s13750-018-0117-3
Warhurst, J.R., Parks, K.E., McCulloch, L., Hudson, M.D., 2014. Front gardens to car parks: Changes in garden permeability and effects on flood regulation. Science of The Total Environment 485–486, 329–339. https://doi.org/10.1016/j.scitotenv.2014.03.035
Weisser, W.W., Hauck, T.E., 2017. Animal-aided design - using a species' life-cycle to improve open space planning and conservation in cities and elsewhere. bioRxiv. https://doi.org/10.1101/150359
White, J.G., Antos, M.J., Fitzsimons, J.A., Palmer, G.C., 2005. Non-uniform bird assemblages in urban environments: the influence of streetscape vegetation. Landscape and Urban Planning 71, 123–135. https://doi.org/10.1016/j.landurbplan.2004.02.006
Williams, N.S.G., Jeremy Lundholm, MacIvor, J.S., 2014. FORUM: Do green roofs help urban biodiversity conservation? Journal of Applied Ecology 51, 1643–1649. https://doi.org/10.1111/1365-2664.12333
Wong, N.H., Chen, Y., Ong, C.L., Sia, A., 2003. Investigation of thermal beneÿts of rooftop garden in the tropical environment. Building and Environment 10.
Wong, N.H., Tan, A.Y.K., Tan, P.Y., Wong, N.C., 2009. Energy simulation of vertical greenery systems. Energy and Buildings 8.
Yang, L., Zhang, L., Li, Y., Wu, S., 2015. Water-related ecosystem services provided by urban green space: A case study in Yixing City (China). Landscape and Urban Planning 136, 40–51. https://doi.org/10.1016/j.landurbplan.2014.11.016
Yao, L., Chen, L., Wei, W., Sun, R., 2015. Potential reduction in urban runoff by green spaces in Beijing: A scenario analysis. Urban Forestry & Urban Greening 14, 300–308. https://doi.org/10.1016/j.ufug.2015.02.014
Ziter, C., 2016. The biodiversity–ecosystem service relationship in urban areas: a quantitative review. Oikos 125, 761–768. https://doi.org/10.1111/oik.02883